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(From the *Cleveland Plain Dealer*, March 21, 1929)

"HOWE RESIGNS AS CASE HEAD. WICKENDEN NAMED AS SUCCESSOR"

"Dr. Charles Sumner Howe, for the past twenty-seven years President of Case School of Applied Science, has resigned from the leadership of Case, effective at the end of the present college year, August 31.

"His retirement removes from the presidency of Case a man universally recognized as an outstanding leader in the field of education. He has been described by a friend as a mellowed Yankee, reared and educated in the traditions of New England and trained in the educational and industrial ways of the west.

"At the same meeting of the trustees at which the resignation was accepted Dr. William Elgin Wickenden, Director of Investigations for the Society for the Promotion of Engineering Education, was selected to succeed Dr. Howe, beginning at the start of the next college year.

" 'Dr. Wickenden was chosen only after a long and careful survey of available men,' Frank A. Quail, President of the Case Board of Trustees, said last night. 'He is young and energetic, a scholar and an administrator,' Quail said. 'Probably no one in the country knows more about engineering education that he—more about the history of engineering schools, their requirements, and their curricula. He has a wide engineering education. His experience in personnel work and in the field of business has fitted him ably for the administrative duties his office will require.

" 'Case has had two notable presidents—Dr. Cady Staley and Dr. Howe—and Dr. Wickenden will prove a worthy successor to this pair.'

"As president of Case Dr. Howe has earned a position of distinction and affection in the educational and cultural life of the city. He has lent his support to innumerable civic

undertakings. His name usually has been found enrolled in support of most of the city's artistic and cultural projects.

"Under his leadership Case has made great strides both materially and scholastically. During his administration Case has climbed to an enviable rank among the engineering schools of the country, being ranked among the first four or five. The physical property of the institution has been enlarged materially. . . .

"On January 1, 1905, he (Dr. Howe) was appointed on the City Educational Commission to look into the curricula of our grade and high schools and determine whether teacher and pupil are overburdened with subsidiary work and to make such recommendations as their finding of facts would warrant.

"Out of the activities of this commission the technical and commercial high schools, the revised normal school course, night high schools, and many other changes in the city school system were evolved.

"Two years ago he was awarded the distinguished service medal by the Chamber of Commerce for outstanding civic service.

"William Elgin Wickenden, who will succeed Dr. Howe, is an example of the university professor who has combined teaching with success in the business world. It is understood that fact made his selection all the more agreeable to the Case Trustees."

THE SUCCESS OF THE SUMMER SCHOOL FOR ENGINEERING TEACHERS

BY DEXTER S. KIMBALL
President of the Society

It should be a source of satisfaction to the members of the Society that the Summer School for Engineering Teachers, started in 1927 and now in its third year, is showing such clear indications of approval on the part of those who know of it.

These sessions which are devoted to the aim of bringing about improvement in teaching engineering were so lacking in precedent or model in this country when they were begun that they were properly regarded for the first year or two as an experimental venture, and were watched as such. Everyone seems to have recognized the desirability of instituting some means of endeavoring to accomplish the ends set for the school, but it was not so certain how the venture would succeed.

It seems fair now to conclude that the school is well launched on a successful career. The sessions have already been attended by no fewer than 175 teachers, and the directing and teaching staffs have numbered over one hundred. It has been the custom at the conclusion of each session to ask those who have attended, members and staff alike, to write letters of comment and criticism on the work. They have been urged to give the frankest possible statements of their views, to point out elements of weakness and to suggest modifications of plan or method. The letters that have been received in response to these requests constitute a remarkable testimonial to the value of the enterprise; for while some features are pointed out that might be improved, some are mentioned that might be eliminated, and others are suggested as possible additions to the programs, nevertheless, the work as a whole is regarded as so highly valuable that no one could fail to reap substantial benefits from it.

Each year the teachers who have attended have been going back to the colleges with which they are connected and have been giving their experiences and impressions to their as-

sociates. The summer school has formed a topic of discussion at meetings of local sections and chapters of the Society, as well as in faculty meetings, departmental conferences and the like. Evidently the reports have been favorable ones, for this year applications have been coming in from colleges previously represented at an unprecedented rate. In spite of the fact the limit of attendance for the session on mechanical engineering to be held at Purdue this summer has been made seventy five, nearly double that of any one previous session, the limit of enrollment has already (February) been reached and a difficult situation has arisen by reason of the large number who desire to attend.

Numbers, of course, are not the only criterion of success of such an enterprise as this, yet if the work had not proved of value to those who have attended it is not difficult to imagine what the effect upon this year's registration would have been.

Another index of approval is found in the fact that already two groups of teachers, those in mathematics and in graphics, have expressed the desire that summer sessions devoted to their subjects be held in the near future. Another is in the fact that the teachers of mechanics, led by some of those who attended the sessions of 1927 as members or staff, are to hold their own session on methods of teaching mechanics at about the time of the annual meeting at Columbus this June. Another indication is given by the fact that some of the engineering colleges are beginning to offer special programs for teachers of engineering during the summer for academic credit, such as those recently announced by the University of Michigan.

The members of the Society should have a genuine sense of gratification in these evidences of the general approval with which its Summer School has met, not only because of the work itself but also because it denotes an increasing desire on the part of teachers of engineering to solve the problems with which they are confronted. It should give us increasing confidence that these problems will be solved. It is to be hoped that we may all do whatever we can to insure the continuation of the work which the Summer School has begun.

THE PROGRAM OF THE 1929 SESSION OF THE SUMMER SCHOOL FOR ENGINEERING TEACHERS

By

H. P. Hammond, *Associate Director of Investigation*

A brief description of the program of the session of the Society's Summer School on the teaching of mechanical engineering, to be held at Purdue University this year, and a tentative list of the teaching staff was published in the January, 1929, number of the Journal. Since then the staff has been completed by the addition of two members to the Machine Design Division: Harold V. Coes, Industrial Engineer, Ford, Bacon and Davis, who will lecture on materials handling equipment, and H. A. Huebotter, Chief Engineer, Butler Manufacturing Company, who will lecture on internal combustion engine design. The program has also been completed and is printed below.

Very heavy enrollment in the Summer School has made advisable an increase in the limit of attendance from seventy-five to ninety. The latter figure, however, is the maximum number that can be admitted due to certain definite limitations. At present, April 15th, the registration has been completed, but it is probable that a few withdrawals will leave vacancies which may be filled from among those whose applications are submitted earliest after the publication of this notice.

The complete list of members of the teaching staff, except for the two additions above mentioned, will be found in the January number of the Journal, and is not reproduced here for that reason. General information concerning registration, living accommodations, and the like is given, however, for the benefit of those who expect to attend.

PROGRAM

WEDNESDAY, JUNE 26

P.M. Registration.

THURSDAY, JUNE 27

8:00 A.M. Registration.
9:00 A.M. Opening Session; Dean A. A. Potter presiding.
Remarks and Announcements ..... H. P. Hammond
Present Trends in Higher Education ..... Edward C. Elliott
Aims and Purposes of Mechanical Engineering Education .. D. S. Kimball
1:15 P.M. Purposes and Scope of Courses in Heat Engineering
A. A. Potter
2:45 P.M. Inspection of Purdue University Engineering Laboratories
G. A. Young
7:30 P.M. Smoker

FRIDAY, JUNE 28

8:30 A.M. Purposes and Scope of Courses in Mechanism and Machine Design ..... O. A. Leutwiler
10:15 A.M. Psychology of the Learning Process ..... C. H. Judd
1:15 P.M. Purposes and Scope of Courses in Production Engineering ..... D. S. Kimball
2:45 P.M. The History of Mechanical Engineering ..... William D. Ennis
7:30 P.M. Round Table Discussion led by ..... C. H. Judd
Topics: Specificity vs. Generalization in Learning
Teaching the Student How to Study

SATURDAY, JUNE 29

8:30 A.M. College Personnel Methods ..... A. A. Potter
10:15 A.M. General Principles of Teaching ..... C. H. Judd
11:30 A.M. Appointment and Organization Meetings of Committees
1:30 P.M. Trip to Turkey Run State Park
Address: The Services of the Engineer in the Development of the Public Estate ..... Richard Lieber

MONDAY, JULY 1

8:30 A.M. How to Conduct Lectures and Recitations ..... C. H. Judd
10:15 A.M. Symposium on Methods of Teaching, Led by
C. H. Judd and G. W. Munro
1:15 P.M. Divisional Meetings:

Heat Power	*Machine Design*	*Production*
Thermodynamics; Principles and Definitions Properties of Gases G. W. Munro	Analysis of Motion R. C. H. Heck	Content of Courses in Industrial Administration D. S. Kimball

2:45 P.M.		
Gas Cycles F. O. Ellenwood	Classroom Methods in Machine Drawing and Machine Design O. A. Leutwiler	Purposes and Scope of Shop Courses O. W. Boston

TUESDAY, JULY 2

8:30 A.M. Factors Influencing the Cost of Power .....C. F. Hirshfeld
10:15 A.M. Financing Manufacturing Enterprises .....G. M. Williams
1:15 P.M. Teaching Values and Costs to Engineering Students .....D. S. Kimball
2:45 P.M. Symposium on the Teaching of Values and Costs, Led by .....D. S. Kimball and A. A. Potter

WEDNESDAY, JULY 3

8:30 A.M. Divisional Meetings:

Heat Power	*Machine Design*	*Production*
Properties of Vapors G. W. Munro	Transmission of Motion R. C. H. Heck	Manufacturing Methods in Production E. Gruenwald
10:15 A.M.		
Vapor Cycles F. O. Ellenwood	Machine Parts O. A. Leutwiler	Content of Shop Courses O. W. Boston
1:15 P.M.		
Flow of Fluids C. H. Berry	Kinematic Principles in Machine Design R. C. H. Heck	Distribution F. C. Hockema

2:45 P.M. Steam Prime Movers .....C. F. Hirshfeld
7:30 P.M. Trends in Power Plant Development in the United States and Europe .....C. F. Hirshfeld

THURSDAY, JULY 4

PICNIC AT ROSS CAMP

FRIDAY, JULY 5

8:30 A.M. The Fundamentals of Management Applied to Industrial Enterprises .....L. P. Alford
10:15 A.M. Fuels and Combustion .....W. J. Wohlenberg
1:15 P.M. Divisional Meetings:

Heat Power	*Machine Design*	*Production*
Heat Reaction in the Boiler Furnace W. J. Wohlenberg	Machine Parts O. A. Leutwiler	Organization for Executive Control L. P. Alford

2:45 P.M. Applications of Mechanics to Machine Design ..O. A. Leutwiler
6:00 P.M. Dinner Meeting. Management's Responsibility for Labor Administration in Industry and Its Relation to Engineering Education .....Sam A. Lewisohn

SATURDAY, JULY 6

8:30 A.M. Materials in Machine Construction .....H. F. Moore
10:15 A.M. Divisional Meetings:

Heat Power	*Machine Design*	*Production*
Economics of Heat Transfer W. J. Wohlenberg	Teaching of Materials in Machine Design H. F. Moore	Organization for Production Control L. P. Alford

MONDAY, JULY 8

8:30 A.M. Purposes and Scope of Mechanical Engineering Laboratory Courses .....G. A. Young
10:15 A.M. Divisional Meetings:

Heat Power	*Machine Design*	*Production*
Steam Generating Equipment C. H. Berry	Principles of the Design of Machine Tools E. A. Muller	Plant Layout and Design J. W. Roe
1:15 P.M. Steam Power Auxiliaries C. H. Berry	Design of Machine Tools; Details E. A. Muller	Power Requirements J. W. Roe

2:45 P.M. Methods of Mechanical Engineering Laboratory Courses (with demonstrations)
G. A. Young, G. W. Munro, F. C. Hockema, H. L. Solberg
6:00 P.M. Reception and Dinner to the Members of the Council of the American Society of Mechanical Engineers.
7:30 P.M. Symposium: The Influence of Standardization on the Mechanical Industries, Conducted under the Auspices of the A.S.M.E. Standardization Committee.

TUESDAY, JULY 9

8:30 A.M. The Teaching of the Principles of Automotive Engine Design .....C. B. Veal
10:15 A.M. Metering in Power Plants .....E. G. Bailey
1:15 P.M. Internal Combustion Engine Design .....H. A. Huebotter
2:45 P.M. Divisional Meetings:

Heat Power	*Machine Design*	*Production*
Steam Generating Equipment Design E. G. Bailey	Steam Generating Equipment Design E. G. Bailey	Job Standardization J. W. Roe

(July 10 to 12 inclusive will be spent at the Hawthorne Works of the Western Electric Company.)

WEDNESDAY, JULY 10

9:00 A.M. Organization Plan of the Hawthorne Works .....C. L. Rice
9:45 A.M. General Description of the Hawthorne Physical Plant and Product .....G. A. Pennock
10:30 A.M. Principles of Production Control .....C. G. Stoll

11:15 A.M. Production Control as Applied to a Selected Unit of Product; Part I (with demonstrations in the lecture room) ..... W. L. Robertson
12:30 P.M. Lunch
1:30 P.M. Inspection of manufacturing processes, illustrating the lectures of the morning.

THURSDAY, JULY 11

9:00 A.M. Purchasing Policies ..... J. W. Bancker
9:45 A.M. Materials: Purchasing, Handling and Storage Methods E. M. Hicok
10:45 A.M. Inspection and Testing of Materials and of Product .. E. D. Hall
11:30 A.M. Description of Production Control as Applied to One Selected Unit of Product; Part II ..... W. L. Robertson
12:30 P.M. Lunch
1:30 P.M. Inspection of Manufacturing and Materials Processes, illustrating the lectures of the morning (with special reference to special machines and tools)
7:30 P.M. Basic Principles of Personnel Administration ... F. W. Willard
Personnel Organization and Practices of the Hawthorne Works .. H. C. Beal
Recruitment and Development of Engineering College Graduates in the Bell System ..... R. I. Rees

FRIDAY, JULY 12

9:00 A.M. Cost Control Methods ..... J. M. Stahr
10:00 A.M. The Uses of the Product of the Hawthorne Works ... W. O. Kurtz
10:45 A.M. Manufacturing Development ..... D. Levinger
11:45 A.M. Developmnet of Wire Drawing Methods ..... J. R. Shea
12:30 P.M. Lunch
1:30 P.M. Inspection of Wire Drawing and Cable Manufacturing Plant

SATURDAY, JULY 13

8:30 A.M. Reports of Committees:
Pre-requisites
Inspection Trips
10:00 A.M. The Industrial Revolution ..... J. W. Roe
11:00 A.M. Variables of Teaching in Technical Schools .. Edward C. Elliott

MONDAY, JULY 15

8:30 A.M. Recent Developments in the Application of Mechanics to Machine Design ..... S. Timoshenko
10:15 A.M. Administration of Mechanical Engineering Shop Laboratories ..... Edward F. Miller
11:15 A.M. Trends in Design of Prime Movers ..... F. Hodgkinson
1:15 P.M. Training of Designers:
Qualities They Should Possess ..... F. Hodgkinson
Methods of Training ..... S. W. Dudley
2:30 P.M. Divisional Meetings:

Heat Power	*Machine Design*	*Production*
The Teaching of Heating, Ventilation and Refrigeration Edward F. Miller	Balancing S. Timoshenko	Economics of Tools and Equipment J. W. Roe

7:30 P.M. Organization and Administration of Mechanical Engineering Departments .....Edward F. Miller

TUESDAY, JULY 16

8:30 A.M. Modern Methods of Stress Analysis .....S. Timoshenko
10:15 A.M. Organization of Courses in Mechanical Engineering Subjects for Non-Mechanical Engineering Students
S. W. Dudley and Edward F. Miller
11:15 A.M. Research in Mechanical Engineering.....A. A. Potter
1:15 P.M. General Session on Mechanical Engineering Laboratory Courses, including Report Writing
Edward F. Miller, S. W. Dudley, G. A. Young, H. L. Solberg
2:45 P.M. Mechanical Laboratory Test Demonstrations .....G. A. Young
7:30 P.M. The Work of James Watt and Its Influence .....I. N. Hollis

WEDNESDAY, JULY 17

8:30 A.M. Reports of Committees: (Divisional Meetings)

Heat Power	*Machine Design*	*Production*
Heat Power Courses for Non-mechanical Engineers	Purposes and Methods of Design Courses	Aims and Methods of Shop Courses

10:00 A.M. Fundamental Principles of Material Handling, Their Effect upon Industrial Plants and Economic Production .....Harold V. Coes
11:00 A.M. Committee Reports:
Values and Costs
Teaching of Management Courses
1:15 P.M. Reports of Committee: Laboratory Instruction
2:30 P.M. The Contribution of Willard Gibbs to Thermodynamics .....John Johnston
6:00 P.M. Dinner Meeting. Speakers:
David E. Ross, John Johnston, W. E. Wickenden

THURSDAY, JULY 18

8:30 A.M. Report of Committee: The Teaching of Personnel Administration
9:15 A.M. Mechanical Engineering Problems in Aviation
Edward P. Warner
10:30 A.M. Personal Elements of Efficient Instruction ...Edward C. Elliott
11:30 A.M. Report of General Committees
12:00 M. Adjournment

GENERAL INFORMATION

HEADQUARTERS

The headquarters of the School will be on the second floor in the South Wing of the Civil Engineering Building of Purdue University. The lecture

hall, class-rooms, offices for members of the staff and conference rooms are provided in this building. The Civil Engineering Building is located on the East side of the Purdue University Campus, with entrances from the Campus and from Grant Street.

REGISTRATION

Registration will be held at the headquarters of the School on the afternoon of Wednesday, June 26th, and at 8:00 A.M. on the morning of Thursday, June 27th. The registration fee of Ten Dollars is to be paid at that time. Checks should be made payable to the Society for the Promotion of Engineering Education.

TIME

Central Standard Time is used in and around Lafayette.

ROOMS AND BOARD

Franklin Cary Hall is being reserved for the members of the staff of the Summer School. Provision has also been made in the same building for those who are accompanied by their wives. A charge of Forty-Five Dollars per person will be made for room and meals for the three weeks of the Summer School.

Rooms may be occupied at any time beginning on the morning of Wednesday, June 26th. The first meal will be served at 5:30 P.M. on June 26th and the last one at 12:15 P.M. on Thursday, July 18th.

The University will provide linen, bedding and towels.

Reservations for rooms should be made through Dean A. A. Potter, Purdue University, West Lafayette, Indiana. **Reservations should be made by June 1st.**

MAIL

Members and staff may have mail addressed to them at Franklin Cary Hall, West Lafayette, Indiana.

HOW TO REACH LAFAYETTE AND PURDUE UNIVERSITY

Lafayette may be reached from Chicago by way of the C. C. C. & St. L. (Big Four), by the Monon Route, or by buses; from Indianapolis by way of the Big Four, electric traction line or buses; from Detroit and St. Louis by way of the Wabash; from Louisville by way of the Monon and from Ft. Wayne or Logansport by electric traction or Wabash.

Lafayette may be reached by automobile on U. S. Highway 52 and by Indiana State Roads 26 and 43. These roads are excellent.

Purdue University is in West Lafayette, about one mile from the railroad stations. The campus may be reached on a west-bound "University Street" or "Purdue Only" car. Leave the car at Grant Street for the Civil Engineering Building. Franklin Cary Hall is at the end of University Street and may be reached by "University Street" west-bound car.

RECREATION

Two golf courses—one in Lafayette and the other in West Lafayette—will be available without charge to the members and staff of the Summer School group. Tennis courts are available. Special picnics and other recreational facilities are being planned by the University.

TRIP TO THE HAWTHORNE WORKS OF THE WESTERN ELECTRIC COMPANY

The Western Electric Company will provide bus transportation to and from the works and the group will be the guests of the Company at the Graemere Hotel.

COLLECTED PAPERS OF THE ELECTRICAL ENGINEERING SESSION OF THE SUMMER SCHOOL FOR ENGINEERING TEACHERS, JULY, 1928

The following pages give condensed versions of a number of lectures delivered before the Electrical Engineering Session of the Summer School for Engineering Teachers conducted by the Society at Pittsburgh, Pennsylvania with the joint cooperation of the University of Pittsburgh and the Westinghouse Electric and Manufacturing Company. Limitations of space make it necessary greatly to condense the papers published herein and to omit many others entirely. Discussions following the presentation of the papers are omitted for the same reason. The papers selected for publication are intended to represent the various divisions of the Summer School program, but the greater proportion of the space available has been devoted to those relating most directly to the problems of teaching electrical engineering. Other papers not here published are available in manuscript form at the Office of the Director of Investigation, Society for the Promotion of Engineering Education, 33 West 39th Street, New York City, and may be consulted there.

THE PLACE OF ELECTRICAL ENGINEERING IN ENGINEERING EDUCATION

By William E. Wickenden

Director of Investigation, Society for the Promotion of Engineering Education

July 5, 1928

Electrical engineering is one of the two major branches of engineering most recently and directly derived from the root sciences. In almost all of the others, the art grew up first and science followed after, and often long after, with its higher refinements. Invention rather than research has been

their traditional fount of progress. In electrical and chemical engineering the reverse order holds. Contrast the history of the steam engine from Watt to Carnot and Rankine, with that of the dynamo from Oersted, Ampere and Faraday to Gramme and Edison, and you have the case in a nut-shell.

This order of progress from scientific discovery to engineering invention has proved to be extraordinarily fertile and time saving. It is significant that the lapse of time between these two stages is now tending to shrink to the vanishing point. Faraday and Edison were separated by the space of sixty years, while Fleming and DeForest came close on the heels of J. J. Thompson in the development of the audion. In electrical and chemical engineering we have given the world an impressive demonstration of a radically new strategy of progress by throwing over all dependence on sporadic invention and substituting the orderly organized attack of the research laboratory. We who are close to this historic event are likely to miss its significance. Philosophers with a more detached point of view are taking serious notice of it. Note what Whitehead of Harvard has to say in his suggestive work "Science and the Modern World."

> "The greatest invention of the nineteenth century was the invention of the method of invention. A new method entered into life. In order to understand our epoch, we can neglect all the details of change such as railways, telegraphs, radios, spinning machines, synthetic dyes. We must concentrate on the method in itself; that is the real novelty which has broken up the foundations of the old civilization."

Not only is our relation to science closer than that of most other branches of engineering but the same is true of our relation to industry. In general, the industries based on traditional arts are much more aloof from technological education and research than those which have sprung more directly from scientific discovery. Experience makes it clear that industries which are close knit and are grouped in large units of organization are best able to foster research, push engineering development, assimilate young men of scientific and engineering training, and capitalize their services in both

technological and administrative duties. The electrical industries are far in advance in systematic recruiting, in provision for introducing the novice to the practice of the art, and in provision for the orderly extension of his fundamental education. To an equal degree these industries more than all others have been able to give the colleges a definite inventory and the clearest specifications of their needs.

If the electrical industries have sinned against us at all, it has been by attracting many of the more original and dynamic teachers away from college posts. That this policy has been justified by its immediate fruits, it would be hard to deny. What its ultimate fruits may be, in consequence of the possible drying up of the springs of inspiration in the colleges, remains in doubt.

Unless the teacher of electrical engineering is familiar with conditions in other areas he is unlikely fully to appreciate the advantages which surround his work. He is under less pressure to teach the art and has greater freedom and incentive to stress the science of his subject; he knows better what subsequent training the employer may be depended upon to provide than any of his colleagues. These conditions go far to remove the most confusing problem of engineering education which is undoubtedly that of working out an effective adjustment between the training given in college and that which comes after.

Turning from our external relations to matters of educational content and process, we ought to stress the almost incomparable advantage of a rigorous and logically developed body of fundamentals, based on a small group of observed phenomena, a small group of generalizations of physical science, a rational system of units and a precise technique of measurement. Most of our science is built up systematically around the geometrical properties of spacial configurations. There has come down to us from Faraday a geometrical imagery of fields of force and flux, to picture the space distribution of stresses and strains, which is a visualizing and analytical aid of incomparable elegance and convenience. Furthermore, we have to deal with physical media of such

uniformity that, with the exception of certain dielectrics and a few magnetic materials, uncertainties arising from physical non-homogeneity are largely eliminated from our analyses. For the most part we have to do with relatively precise and predictable situations, where theory and fact literally coincide within engineering limits of precision. We have at our service a varied assortment of powerful and refined mathematical tools. Our problems of design are largely problems of rational analysis, to be worked out at a desk, rather than problems of configuration to be worked out on a drawing board and by empirical testing of models. From the viewpoint of teaching, these are inestimable advantages. A sound experience of the art of engineering can scarcely be gained on college premises, but a sound experience of the science of engineering can be gained there better than anywhere else. The more closely the two conform, the more nearly ideal the educational situation.

The practical benefits arising from these fundamental factors are not far to seek. Our curriculum may be likened to a tree with a long trunk, from which the branches divide at a high level. In no other branch of engineering is the common core of fundamental principles so extended and so unified. Teachers of electrical engineering have the maximum unity of interests. When the student of civil engineering has completed his work in mechanics, he passes from the main scientific trunk to its several branches. Our situation in electrical engineering is more favorable to a cumulative scientific discipline and a unified rational groundwork before specialization. Against this advantage we must frankly weigh the weakness of the typical graduate in electrical engineering on the side of material forms and structures, processes of fabrication, and common sense expedients for commonplace engineering problems; as a novice he is likely to go about seeking unduly complex and often unduly precise ways of doing fairly simple things.

Granting that the intangible nature of many electrical phenomena and their indirect sense perception add to our difficulties and put the student's conceptual capacity and powers

of visualization to a rather severe test, yet we ought to be able to do about the best job of scientific grounding of any of the major engineering departments. There is no really valid reason why our curricula should suffer from serious overcrowding or from excessive fragmentation of work. Overcrowding arises from efforts to include a fairly extended introduction to the art rather than from an effort to do justice to the underlying sciences. Consistent application to the dictum: "Do not try to learn in college what you will have a good chance to learn somewhere else," would cure most, if not all, of these ills. A four-year college program affords a reasonable quota of time for either of two alternatives. One is a fairly broad grounding in the engineering sciences and related humanistic studies, with a definite orientation to some chosen major branch of engineering, and with a fairly extended illustration of their application in some principal division within that branch. The other alternative is to confine the treatment of basic scientific and humanistic subjects within strictly utilitarian limits, similarly to limit the technical sciences not directly tributary to the major professional branch, and to give as extended treatment as practicable to all the major divisions of professional practice. The weight of engineering opinion inclines strongly toward the former alternative.

The best education is not acquiring information, but learning how to learn. To learn the art of applying principles, to gain insight into methods of engineering analysis, to grasp the criteria of engineering decisions, one does not need to familiarize himself with a wide range of practice. He will do better to explore some one field more thoroughly, learning the method of some master mind. Better one major course exemplifying real engineering method under one creative man —a Lamme if possible—than years of scattered hack work.

It is now generally agreed than an educational program ought to be designed with active regard for the life situations in which the student will probably find himself, rather than from mere subjective considerations of the presumptive value of this or that subject or discipline. The writer does not,

however, wholly follow the thinking of those who hold that the curriculum should be built up by a direct synthesis of detailed analysis of the jobs in which novices fresh from college begin their active work. He would apply the test of usage in a broader way and with a freer hand.

(The speaker then rapidly reviewed some of the available data concerning the connections and careers of graduates in electrical engineering, and continued his remarks as follows:)

It seems clear that a somewhat higher proportion of mature electrical engineering graduates engage permanently in technical and operating activities than is the case among graduates in general, that a somewhat smaller proportion pass into administrative posts or the personal ownership of a business, and that relatively more are engaged in commercial activities. The data clearly indicate that an overwhelming proportion of graduate electrical engineers are associated with corporate organizations. It would seem that the relations, routines, forms and procedures of corporate organizations are quite as important to these men as working tools as is the technique of electrical engineering, also that the typical modes of thought and criteria of decisions which govern their daily work are quite as largely economic as they are scientific in quality.

It would seem that there is quite as much warrant for making a course in electrical engineering a preparatory discipline for line and staff officers of electrical industry as there is for making the course at West Point such a discipline for future officers of the army. West Point is a blanking-out process. The more detailed formation of the officers comes in the service schools after the novice has become oriented by preliminary field experience to a particular arm of the service. Having in view the nature of an officer's career and the more specialized training yet to come, West Point does not limit its concern to the technic of military operations, but devotes a generous share of attention to the history, traditions, ethics and social responsibilities of the profession of arms.

In the light of the present and prospective function of electrical engineers, is the perspective in engineering education what it should be?

To the speaker it appears that one of the most urgent problems in engineering education is that of giving it an economic basis which is just as sound and effective as its scientific basis. There appear to be two quite distinct problems involved in this connection. One relates to economics as a science of wealth, and the other to engineering economy as a concrete effort to get the best ratio of utility to cost. There is a group of the more progressive economists at present who are trying to make their subject more concrete and realistic, but the real crux of the problem lies elsewhere. It is to provide an economic grounding which is functional in relation to engineering; so to interweave it that criteria of economy for the solution of engineering problems may be perceived and the technic of economic analysis may be built up concurrently with the technic of physical analysis. This end cannot be accomplished by adding to the courses in formal economics or by borrowing informational material from the curriculum in business administration. The desired result must be gained chiefly through the work of the regular engineering teachers in the regular technological courses.

As to the regime of work in engineering colleges, it appears to the speaker that this should be considered in two divisions: the first two years and the second two years of the curriculum.

What seems to be needed in the first two years is not some radical change of plan, but better personnel supervision, better orientation to college life and work, better adjustment of work loads, closer coordination between subjects, and most of all more effective teaching.

The regime of our upper years seems open to radical criticism. The modes of instruction suited to the lower years tend to persist, so that the work of upper classmen is often professional in content, but not in spirit and method. No one seems to complain that the engineering graduate shies at work. What he more often lacks is perspective, imagination and initiative.

There is a disquieting suspicion among us that much of our effort is not really creative education, from which a method can be carried over into after life, but just high-grade routine

training. The road to betterment seems to be four-fold. The first path leads to a senior grade of professorship that represents a career that will attract and hold men of distinguished scholarly attainments, responsible experience, creative capacity and notable teaching ability—a career that men will deliberately choose and for which they will strive and prepare, rather than one into which men will drift in default of any positive decision. Considering the present opportunities in practice for creative work and personal distinction, the teaching function will seldom hold such men by its appeal to artistry and altruism alone. We need urgently to invest these major posts with larger responsibilities for the direction of subordinates, larger resources for creative work and larger rewards, both monetary and intangible.

The second path breaks away from the imitative quality of our teaching and the over-dominance of textbook traditions. From the earliest days, American engineering educators have been regarded primarily as teachers by career, rather than creative technologists. Few have thought it amiss that they should be required to teach far beyond the limits of their active experience. In far too many cases they have been expected to teach far beyond the limits of adequate professional prepartion. Of necessity they have had to depend on second-hand, rather than first-hand materials. Lacking any formal introduction to the teaching art, they have taught as they were taught. As a consequence there has grown up a fairly fixed pedagogic tradition, rather than a fluid one, growing out of a living and changing art.

A third path to progress lies in the direction of larger units of work assignment, more autonomy for the upper class student and more comprehensive methods of evaluating achievement. Tradition has plainly gone askew among us in placing virtually the whole burden of initiative in the learning process on the teacher, making him a combination of pedagog, disciplinarian, inspector and accountant.

The things we give our students to do are not often calculated to stimulate the imagination or appeal to a spirit of emulation. For a lesson in a more stimulating method we

may do well to consider the educational methods of architecture and the fine arts. The essence of the "atelier" method is that, after the student has been sufficiently disciplined in the rudiments, he is set to creating original art under the guidance and criticism of a creative artist, who seeks to impart not only technic to the novice, but equally to school him in the art of self-criticism and self-improvement. The whole appeal of the system is to self-expression. As in golf, the student is always playing against his own best record.

The fourth path to progress which the writer would suggest is the working out, possibly first in electrical engineering curricula, but ultimately in all, a bilateral scheme of options divided on functional lines, one of which stresses the older, historic function of *originating* new structures, machines, installations and processes, and the other the more recent and emerging engineering function of *operating* going installations and services.

In conclusion we may venture an observation on the significance of electrical engineering in modern society. Electricity has been suggestively called the money of energy—a medium of transmission and exchange capable of indefinite subdivision for our most delicate tasks, equally capable of indefinite aggregation for our most herculean tasks; sensitive to control, unsurpassed in swiftness of motion, capable of being charged with extreme concentration for economy of transmission, lending itself to accumulation, storage and recovery, and capable of transformation into any other form of energy value. Through use of electricity, society has passed out of a primitive stage of direct barter, in its use of energy, to all the refinements, complexities and conveniences of an elaborate system of exchange. What this change portends in human values is by degrees being revealed to us.

THE LEARNING PROCESS

By Grover H. Alderman,

Dean of the School of Education, University of Pittsburgh

July 6, 1928

There was a time in the history of higher education when most of our attention was centered on the activities of the teacher. At that time we looked on the student as an individual who possessed a mind like a blank piece of paper upon which the teacher could write whatever he wished. Most of the pedagogical literature of the time followed the Herbartian theory of teaching. The teacher was trained to catch and hold the attention of the student; to present material effectively, to illustrate the facts given, and to summarize and apply each lesson to the lessons which had been previously taught. The teacher, therefore, was the center of attraction about which all other school activities tended to revolve.

Since that time, however, there has been a constant shift in emphasis from the teacher to the student. This change has been brought about by a change in our educational philosophy. We have come to believe that the teacher does not impart knowledge to the student, but rather that the student educates himself. He educates himself by practicing handwriting, by reading in the library, by performing some practical project in electrical engineering, or by thinking through some problem which has challenged his attention. A student is not educated by absorbing passively the lecture which the professor gives, but he educates himself through his own activity which is usually stimulated and directed by a sympathetic co-worker known as the teacher.

Since it is our duty as teachers to stimulate and direct the learning activities of our students, it naturally follows that we cannot direct learning activities economically and effectively unless we understand thoroughly the mechanism of the

learning process. In the school of medicine much time is spent in dissecting the human body so that the function of each bone and of each muscle may be understood. In the school of engineering if you want a student to understand the mechanism of a dynamo, you ask him to take it apart or to test it through experiment. Likewise, in the teaching profession if we are to direct the learning activities of our students, it is necessary that we study the simple nervous system and the reacting mechanisms, so that we may know how each functions in the learning process.

All the impressions which we receive from the outside world are obtained through the ears, the eyes, the nose, the tongue, and the skin. If the end organs are perfect, other conditions being equal, the impulses received from them will be perfect; but if the end organs are defective, our impulses will be impaired accordingly. For more than a quarter of a century public school authorities have been sensitive to the educational problem presented by children who may be defective in their hearing or vision. The public school officials in any important city in America can tell you the number of children with any defect which may interfere with their educational development. This condition, however, is not true in our institutions of higher learning, for it is very seldom that we find any attention given to this important problem. I doubt if many of us here know the students in our classes who have difficulty in hearing us speak, or in reading the examination questions written on the board. There is certainly much truth in the trite statement that a teacher must learn his students before he attempts to teach them.

The central nervous system is so mysterious in its operation that one authority describes it as a switch system of tremendous complexity. The mechanism which makes it possible for one to learn a poem at six and to reproduce it at forty-six is a feat which is almost unexplainable. The mechanism which makes it possible for one to play a piano and to sing a song at the same time so that both will synchronize with a moving picture baffles all understanding. Although we know little

about this mysterious switching system, there are a few facts which should be of special interest to the teacher. First of all, we should remember that the sensory neurones do not make direct contacts with the motor neurones, but instead the endings of each intertwine like the branches of a tree. From the point of view of original nature it is just as easy for a response to be incorrect as for it to be correct. It is just as easy to say seven and eight are thirteen as to say that seven and eight are fifteen, and when the wrong response is made a change of conditions takes place in this switching system to the extent that it is likely to be repeated. The direction of this connecting mechanism so that the correct reaction or bond will be formed is an important part of the teacher's work. A third thought which should be of interest to the teacher is that one reaction does not take place singly and alone, but is usually accompanied by other reactions which may both mentally and physically take place in the form of emotions, feelings, sensations, memories, and ideas. If it were possible for us as teachers to segregate one idea and teach it until it is mastered, our responsibility as teachers would be rather simple. But when it is known that a student learns almost as much from his associates and from his extracurricular activities, the duty of the teacher becomes a very complex affair.

Anyone who has read any book which has to do with the laws of learning knows that the human mind has a tendency to react in such a regular fashion that it is possible for us to derive certain rules or laws. The first one of importance to the teacher is known as the Law of Readiness. Briefly stated, it has been found that when a conduction unit is ready to conduct, conduction by it is satisfying. On the other hand, if something blocks a conduction unit which is in the state of readiness, the result is annoying. This is a very simple law. Anyone knows that it is satisfying to eat when one is hungry, and to rest when one is weary. Likewise, we know that it is very annoying to be unable to move an obstacle when one attempts to push it, or to be held when one wishes to run. The law holds good not only to definite original behavior

series, but also throughout general behavior, and should be recognized by the teacher in his attempt to direct the learning activities of the student. If a boy has studied his lesson diligently and comes to class thoroughly prepared on his assignment, it is certainly annoying to him not to have an opportunity to recite. Likewise it is just as annoying to the student who studies past the midnight hour to prepare for a certain examination only to find that the examination stresses some unimportant section which has not been emphasized in class. The Law of Readiness, therefore, is not a theoretical law which is of interest to the pure psychologist, but is a practical one which should be observed by all teachers.

A second law, known as the Law of Exercise, states that whenever a modifiable connection between a situation and a response is exercised, other conditions being equal, the strength of that connection is increased. This law naturally follows a statement to which I have previously alluded. When it is remembered that unless the student is carefully directed, his response may be incorrect as well as correct, it certainly becomes an important part of the teacher's work to make sure that all reactions when originally studied are correct. Dr. Meyers of the Cleveland School of Education has found that when a student makes a mistake, not only is his answer wrong, but the wrong answer is just as definite and just as positive as it would have been had it been correct.

Many times we, as teachers, get the impression that the problem which we are presenting is perfectly simple and easily understood by each member of our class. Whenever teaching is followed by careful testing, however, it is usually shown that problems which seem perfectly simple to the teacher are misunderstood many times by fifteen or twenty per cent of the class. If this is true, the practice of leaving the lecture room immediately, without giving the student the opportunity to ask questions, should be discouraged. Many times a boy is confident that a certain theorem is understood by every other member of the class and hesitates to take their time to have the problem again explained. If in the first part of the semester this individual could have an opportunity to

ask questions of the instructor immediately after the class hour or during a definite conference period, I am led to believe that this would remove many difficulties which we now experience in our teaching. Under no conditions should any pupil be permitted to leave our class periods with a wrong impression of the lesson which has been presented.

The Law of Forgetting, which is many times included as part of the law which I have just given, states that whenever a modifiable connection between a situation and a response is not exercised during a length of time the strength of that connection is decreased. That is to say, that if a theorem or a law is learned temporarily so that it may be repeated during the recitation hour, it will be of little value to the average student a few days later. Important laws and important theorems, which are to be used in the future in our teaching, should be taught and re-taught until permanency is obtained.

The third law of learning is known as the Law of Effect. This law states that we tend to repeat those reactions which bring satisfaction, whereas we tend to avoid those which tend to bring about an annoying state of affairs. This is a very important law in teaching. Dr. Book in a carefully controlled experiment in teaching typewriting discovered that if one group was told that it was not succeeding, very little improvement was made, while a second group of equal ability improved greatly if it was encouraged from time to time by the teacher. This rule, or the Law of Effect, therefore, should be recognized in planning our teaching technique. There is a great deal of truth in the old saying that "nothing succeeds like success." If teaching can be done in such a way that the student knows that he is achieving something, he will receive a great deal of joy from his work. If, on the other hand he works time after time with no knowledge of his progress, he will become discouraged. The bowler gets a great deal of pleasure in attempting to raise his own record; the golfer will practice many hours in attempting to lower his score three points, and likewise, the student will put forth just as much effort to beat his own record, if the teaching and testing is

done in such a manner that he can readily see that he has accomplished the task which he set out to do.

THE PRINCIPLES OF TEACHING

By Grover H. Alderman

July 9, 1928

There is a tendency in many of our American universities to place too much emphasis on lesson performance and not enough on thoroughness and mastery of the subject as a whole. This is indicated by many of our present-day practices in teaching. For example, we find professors still making daily assignments. We also find these same professors giving two or three days for a review before the final examination is held. This practice suggests that the instructor is of the opinion that the student has not learned the material when it was presented to him for the first time, and it is now necessary that his memory be refreshed before he is requested to write the final examination. This attitude toward partial mastery is further indicated by the marking system which is used in most of our universities. The fallacy in the system is not a hidden one. If you throw a man overboard he will either swim or sink. He cannot swim with *C* or *D* proficiency. If we are grading swimmers, therefore, from the point of view of their being able to save themselves there would be but two points in our grading system.

If we talk with students regarding their work, we shall find that many of them have this "get by" attitude. If a certain student has studied the first two lines of his French lesson and is lucky enough to be the first one to be called upon, he leaves the room with the attitude of a man with a batting average of 1,000. This attitude, which we all admit is the wrong one, will continue just so long as we pass or fail students on their daily recitations and their ability to guess the types of examination questions which the professor is likely to ask.

While it does not fall within the scope of this lecture to discuss the problem of the curriculum, it does seem to me that there is a more definite relationship between the curriculum and efficient learning than we have previously thought. Many times our teaching is inefficient because we are asking the student to attempt to learn too much. Each professor before he teaches the first unit of any course should review the entire course and attempt to eliminate any units which are not absolutely essential. If someone had the power to eliminate one-third of all the material which is now being presented to our university classes, it is the opinion of your speaker that university instruction would be greatly improved. If a certain law or a certain formula is necessary for the training of an engineer, it should be mastered thoroughly before a second unit is assigned. If there are so many units that it is impossible for them to be mastered within the scope of a semester, the entire course should be examined very critically with a view to eliminating the non-essentials. If a law, a formula, or a skill is needed in the training of an engineer, it should be thoroughly taught, and if not, it should be eliminated.

For fear the statement which I have just made may be misinterpreted, I want to stress the fact that the curriculum in any school is a means to an end and not an end in itself. A student learns from his experiences, but he does not necessarily learn all the experiences. In training a high school student to typewrite, we may use many phrases and many sentences so organized that all the various combinations of the alphabet will be included. We are using these phrases and these sentences as exercise so that the student may teach himself how to type; but when he has finally mastered this particular skill, we do not expect that he will remember all the sentences and all the phrases. The number of exercises and the number of phrases used should be sufficient to develop this particular skill so that it will remain with the individual permanently. The curriculum, therefore, is important to the extent that it brings about this mastery or adjustment on the part of the learner.

The teacher's part in bringing about this permanent learn-

ing, which is so essential, is a most important one. We have often heard the statement that "teachers are born and not made." While there may be a certain amount of truth in this, it is my judgment that there is a higher correlation between thorough preparation for one's work and success than we have previously thought. By this term, "thorough preparation," I do not mean the preparation which we usually receive as a student, but rather a thorough preparation of a semester's work before we teach the first unit. If we are beginning teachers, the preparation we put on our courses between now and the first of September will largely determine our success for the first semester. No teacher should attempt to teach any course until he has definitely established objectives for that course. By objectives I mean the knowledge, the skills, the abilities, the attitudes, and the ideals which he hopes to develop as the result of that particular course. After his objectives have been thoroughly established, he should next have each learning unit definitely outlined before making his first appearance before the class. The size of the learning unit is determined by its importance. As one writer has said, it may be so simple as to train the child to say, "I beg your pardon," when he treads on the toes of another, or the unit may be so large or so inclusive as to explain what we mean by this phrase, "The League of Nations." In each case, however, enough time and enough exercises must be given so that the class will have an opportunity to understand and master thoroughly that particular unit before the next one is taken up. As I make this statement I am sure that I hear you say, "What about individual differences?" If our students were all alike in ability and in their previous training it would be an easy task to follow the suggestions which have just been made, but since this is not true, how is it possible for ideal conditions to exist in a class when one student is six times as capable as another. In answering this question, may I remind you that these objectives and these learning units should be compiled for the average student. This is not sufficient, however, since we are no more justified in giving a brilliant student an *A* for doing a minimum amount of

work than we are in giving a slow student a mark of failure for attempting to do the same amount of work. Sufficient exercises and learning units should be planned by the instructor in charge so that this brilliant student will have an opportunity to explore the field more broadly and more deeply than is demanded of the average student. The teacher, therefore, should go before his class in the fall of the year with the minimum essentials thoroughly in his mind, and with his course so thoroughly mastered that he has enough supplementary exercises to challenge the ability of this exceptional student.

How shall we learn about this wide range of abilities which we have just been discussing? Testing in the past has been used as a grading device and not as an instrument of instruction. If we, as teachers, believe that a certain unit of instruction is organized for the purpose of administering or developing certain knowledges, skills, or abilities, we should certainly have a test device to administer to the class to determine whether or not there are members who are already possessed of these desired skills and abilities. It should make no difference to us how the student has acquired any particular information just so that it is learned correctly. In the olden days we attempted to teach children to spell by assigning ten words for each lesson. By following this method of instruction, many children studied words which they already knew how to spell. This resulted in a waste of time for both the children and the teacher. According to the modern theory of instruction, each child is tested before the assignment is made, and by so doing each individual studies the words that are his own particular problem. I have a list of twenty words before me which are considered difficult words for the eighth grade. If I should pronounce these words to this group of university professors, I would find that few of you could spell every word. I would also find that a majority would miss more than half of them, and I am sorry to say that experience in the past has led me to believe that a certain few would miss all of them. If it were our problem this morning to teach each member of the class all of these words in the most eco-

nomical way, the first step in the teaching technique would be to discover the particular words which each man should study. In other words, we should "put the oil where the squeak is." This is sound teaching for the elementary school, and it is just as sound for high school and university. If we follow the technique which I have just described, what would become of our old-time traditional lecture? There are a few men in America who have a right to go before a class and lecture each day throughout the entire semester, but if the field of electrical engineering is anything like the one with which I am associated, these people can be numbered on the fingers of one hand. If a professor is positive that the material which he is presenting has not been printed, he has the right to present it before the class. Again, if he has the ability so to challenge the class that each student will think on the problem he is discussing, then he should be granted the privilege of presenting his material by the lecture method. As the practice is now followed, many professors assign a lesson for the next day, theoretically for the benefit of the student; they then proceed to prepare this lesson which they have assigned and return the next day and recite it before these same students. *If we could have less activity on the part of the teacher and more activity on the part of the student, there would be more learning taking place in our university classrooms.*

INTRODUCTION TO THE TEACHING OF ELECTRICAL ENGINEERING

By C. Francis Harding

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July 6, 1928

Tredgold's definition of engineering is perhaps the best with which to approach the problems connected with the teaching of electrical engineering. He said, "Engineering is the art of directing the great sources of power in nature for the

use and convenience of man." I like the word "art" in this definition. It has the practical, human, and economic touch which is so frequently neglected. Another good statement of the ultimate goal of the teaching of electrical engineering is: "Modern engineering is a combination of science and art by which all strictly material productions that involve construction, either directly or indirectly, and which are serviceable to mankind, are evolved, designed, and materialized."

The raw clay from which we are expected to mold a potential electrical engineer comes to us from a wide variety of heritage, environment and preparatory education. Most of our students are interested; they are ambitious to do something, they hardly know what.

The successful teacher of electrical engineering must *first* receive and become well acquainted with the many varied personalities that come to his classes with widely diversified early training; secondly, he must outline the fundamentals of the subject he is to teach; third, he must correlate the instruction with that with which the student is acquainted; fourth, it is necessary continuously to illustrate and emphasize the practical and economic bearing of these fundamentals upon the future work of the engineer; and lastly, he must determine what progress has been made from time to time, outline the future possibilities, and inspire the student to proceed further.

With these requirements in mind, the problem very naturally resolves itself into the three following subdivisions:

I. The Fundamentals of Electrical Engineering Study,
II. Teaching the Fundamentals of Electrical Engineering,
III. "Application" Courses in Electrical Engineering, Their Purpose and Scope.

The Fundamentals of Electrical Engineering Study

The longer one practices and teaches electrical engineering the more is he convinced that all engineering problems are but special cases involving a comparatively few fundamental laws of physics, mathematics, chemistry, economics and psy-

chology. The first three, *i.e.* physics, mathematics, and chemistry are usually fairly well treated by the average teacher, although the gulf between such subjects and the instruction in the engineering schools is seldom adequately bridged. The very important relation of electrical engineering instruction to the fundamentals of economics and psychology is too frequently neglected.

The effective instructor of electrical engineering must recognize as the result of actual personal experience in practice that all of these fundamentals must be included in practically every teaching exercise and that they must be welded and bonded into every problem of every course. I make no exception to this rule. A graduate of the best school of electrical engineering with all the graduate study appertaining thereto, who is without practical experience is not only inadequate as a teacher but is a menace to the profession. Such an one invariably fails to appreciate the well-rounded economic and psychological problems confronting the engineer and very frequently limits the foundation of his instruction and illustrations to but one or two of the five basic subjects.

But we are expected to outline the ideal and successful course of instruction and to forget, except as a glaring negative example, such a tempting and all too frequent "course of least resistance."

Let us assume that an electrical engineering student is entering the first required course of instruction offered in the electrical engineering department. Such a student, usually in his third year, has previously completed a course in general physics, is probably well along in or is through calculus, has completed general chemistry and possibly some economics and psychology. He is familiar with shop work and shop tools. Such a student is still generally thinking in the abstract or academic language of the galvanometer, the Wheatstone bridge and the Leyden jar. He may be familiar with the definition which he has memorized for a unit of current based upon the deposit of a certain amount of silver per second under certain prescribed conditions, but he is not able

to visualize the thousands of amperes read upon the ammeter of a railway feeder panel.

The most difficult problem of the instructor is that of acquiring an intimate knowledge of the status and boundaries of the student's acquisition of fundamental laws, and of correlating them with the conceptions and applications of those laws which are used as tools by the engineer, but which are often supplied with slightly different handles. Unless this transition from one concept to another is very carefully brought about, the whole picture becomes blurred and indistinct in the mind of the student.

If, in presenting new laws and concepts, the instructor introduces such practical applications as may bond the new to the old and if he goes to the trouble of interpreting the results of the student's knowledge in terms of the common engineering units, this difficulty and confusion may be avoided. The prerequisite course in physics then becomes a real foundation upon which a well-designed engineering training may be constructed.

In presenting some of the fundamental laws underlying the electrical engineering profession, therefore, for your review it will be my purpose to emphasize the fact that they are few in number but that they extend throughout all the range of subsequent engineering application. If the student has been taught to analyze each practical case as it arises and to reduce it to fundamentals, a solution will result that usually may be readily interpreted.

Many examples might be quoted in which the practical problem confronts the student, leaving him to make the analysis and apply the proper law. A series of such practical problems might be used in the *concentric method* of teaching to introduce the few fundamental laws of the magnetic and dielectric circuit. Such a process is of greatest interest and, possibly for that reason, is most readily taught. Many experiences and problems might be cited, however, as in the *"case method"* of teaching law, medicine and economics, without properly uncovering some of the important basic laws underlying electrical engineering. Since the latter are few

in number, the divergent method, with illustrative examples and cross references, is usually found more effective, although it is likely to become more academic and lacking in the interest with which to drive it home.

Suppose we list a few of the fundamental laws, therefore, and indicate their possible ramifications as we follow the divergent, rather than the concentric method.

Whether the magnetic or the dielectric laws of electrical apparatus and circuits are first to be treated in an elementary course, or whether it is practicable to teach them simultaneously, is largely a matter of opinion and custom. The introduction to the division of electricity in physics is sometimes approached from one angle and sometimes from the other. We may start with the discovery of the peculiar magnetic behavior of the loadstone or that of Thales of Miletus that rubbed amber attracts light objects. The former leads, of course, to the well known laws of magnetic polarity, of attraction and repulsion and of the force actions upon the more or less fictitious unit strength magnetic pole. Magnetic fields are mapped, leakage flux is approximately plotted and the direction and force of movement and particularly of rotation of a current-carrying conductor are determined in the magnetic field as the results of early experimental discoveries of Michael Faraday. On the other hand, however, the charge on the pith ball, the resultant induced or bound charged, the Leyden jar, the famous Faraday ice-pail experiment, etc., early acted as a basis for the determination of a standard of electrical polarity, more or less traditionally established as positive and negative, and the recognized relations of current flow from regions of higher to those of lower potential. Whichever one of these developments of the theory is undertaken first in sequence is of little consequence, since the two lines of thought and action must ultimately merge into the modern generator and motor. During the last few years more attention has necessarily been given to the laws of the dielectric circuit. Although it may not be found practical or advisable, in elementary teaching, to carry along as parallel illustrations the problems of the magnetic and dielectric cir-

cuits, sooner or later in the course the close analogy between the two should be pointed out.

For our own consideration, let us take up first that which now seems to be the more simple and logical, *i.e.*, the dielectric circuit. I like to think of such instruction as following outward from a few concise facts and laws at the center along one of many possible radial lines of thought, pausing occasionally to tie acros from one radial concept to another with those intimate cross ties and braces which make up the analogous systematically designed and constructed spider web known as engineering education. It should be our endeavor to grasp first the conception of the completed web as a whole, in order that our students may early recognize its symmetry, its design, its rugged supports and its ever-increasing area of contact. The analogies to the magnetic circuit should, therefore, be indicated from time to time in order that the same laws may be recognized as having application to both circuits and therefore not considered by the student as just another series of definitions to learn and another set of formulae to memorize.

Suppose then, that we have established at some prescribed point, by some previously well-known means, such as a rubbed glass rod, an electrical potential above surrounding objects. Our first demonstration should be that of distinction between materials or surfaces which quickly or very slowly permit such a charge to leak away. Conducting and insulating materials may then be classified, if it is made clear to the student that the distinction is quantitative only. In other words, the leakage conductance and *IR* drop in potential over a high-voltage insulator, a wooden insulator pin or pole, should be recognized as precisely the same qualitative phenomena, but differing only quantitatively from the conductivity of the railroad rail, the copper bus bar or feeder, and the large voltages due to heavy currents flowing therein.

Following the very early experiments with charged particles, and his measurement of their force action, Coulomb, in 1785, arrived at the very simple, yet extremely important, inverse-square law of electrostatic forces.

Coulomb's law states, (1) that such a force varies as the product of the charges, and (2) inversely as the square of the distance between the centers of the bodies.

Faraday, in 1837, discovered that the magnitude of the force between two such bodies, electrified with given charges, depends also upon the dielectric medium in which the bodies are immersed.

These three laws, in the form of an equation, may be represented as follows:

$$F = \frac{Q_1 Q_2}{kr^2},$$

where k is a constant depending upon the dielectric medium.

Thus the student may measure electrical charges, as did Coulomb and Faraday, just as the weight of small bodies may be measured. He then becomes familiar with the electrostatic unit of electrical quantity.

Having found that dry air, a vacuum, or other dielectric materials, will enable a difference of potential to be maintained between two parallel conducting plates, the stress in such a dielectric placed in the center of plates of large area and relatively small spacing may be considered to be uniform and may be represented by fictitious lines drawn perpendicular to the plates. The mechanical force exerted between the plates is determined by either one of two fundamental concepts:

(1) In the case of a displacement, consisting of pure translation of one conducting plate through a distance dx toward the second conducting plate, in such a manner as to keep the quantity of charge q constant, but with an increase of capacitance dc, the decreased amount of stored or potential energy may be equated thus:

$$\frac{Q^2}{2c} - \frac{Q^2}{2(c+dc)} = \frac{Q^2 dc}{2c^2}.$$

This decrease in stored energy may be equated to the mechanical work done in moving one conducting plate through the distance dx. If F be such a force, tending to move the conductor,

$$F dx = \frac{Q^2 dc}{2c^2}$$

or, in practical units of dynes, volts, farads and centimeters

$$F = \frac{E^2 dc}{2dx} \times 10^7.$$

(2) In a similar manner, if the difference of potential E between the plates is held constant, a corresponding expression results for the force.

Here we have a basis for the determination of the average attraction of electrons or protons, of small charged particles or of relatively large conductors, if the field strength be considered uniform and if the dielectric remains homogeneous and unchangeable.

Returning to the uniform dielectric field, however, the laws of Gauss augmented by the equations of Maxwell, Poisson and Laplace may be applied adequately to determine the electrical intensity at a given point in such a field.

Gauss, in 1813, when depicting the gravitational field, pointed the way to the solution of similar centrally directed vector fields within which the inverse square law is applicable as follows:

The force at a distance r due to a point or unit charge q is

$$F = \frac{q}{Kr^2}.$$

If now we assume any imaginary area or closed section of a surface surrounding the charge q and if we let N represent the normal outward component of the force due to q at any point P on the imaginary surface with ds the area of a small portion of the surface at P and θ the angle between N and f;

$$Nds = \frac{q}{Kr^2} \cos\theta \, ds,$$

whence

$$\int\int KNds = 4\pi q.$$

Since KN is the normal induction across the surface at point P, this equation indicates the mathematical basis for the well-known law that the surface containing the charge q is equal to $4\pi q$.

With additional charges located inside the surface the law becomes by analogy:

$$\int\int KNds = 4\pi\Sigma q.$$

Such is called a Gauss surface and when selected upon various well-known simple areas the following corollaries result:

Consider a plane conductor or plate carrying a uniform charge of σ units per sq. cm. Let the Gauss surface be of cylindrical form with the sides of the cylinder parallel to the lines of force, with one end of the cylinder of cross-sectional area S within the conductor and the other extending a short distance outside of but near to the conductor and into the dielectric of constant K. The charge within the cylinder is σS. The normal induction outwards from the cylindrical surface of the Gauss cylinder is zero, because the sides are lines of force. Similarly the force outward upon the circular sectional area within the conductor is zero. Upon the end of the cylinder or Gauss surface extending into the dielectric, however, the integral of normal induction is the same as that of the conductor surface and may be called F. Thus

$$\int\int KNds = KFS = 4\pi\sigma S$$

or

$$F = \frac{4\pi\sigma}{K}$$

is the force just outside the surface of a conductor carrying a charge of units per unit area.

The capacity per sq. cm. of parallel conducting plates of large area, separated by a relatively small distance d, becomes

$$C \text{ (per sq. cm.)} = \frac{\sigma}{Fd} = \frac{\sigma K}{4\pi\sigma d} = \frac{K}{4\pi d}$$

or

$$C = \frac{KA}{4\pi d}.$$

This value of 4 resulting from the spherical surface integral of the solid angle about the imaginary and theoretical unit

charge has always been a stumbling block to the student of both the dielectric and magnetic circuits. Many would prefer to include it as a numerical coefficient and absorb it in the constant K or its equivalent; others would introduce new units taking the 4 into the definition of the unit.

Similarly in the magnetic circuit, where the Gauss theorem was first applied for the uniform magnetic field, we have the familiar expression

$$F = \frac{M_1 M_2}{\mu d^2},$$

where F is the force between two similar magnetic poles of strength M_1 and M_2, separated by a distance d, and with the permeability μ dependent upon the medium within the magnetic field in which the force is required to act.

If a unit test magnetic pole, free to move, be assumed of strength M corresponding to the unit charge of the dielectric circuit, this becomes the analogous expression:

$$\mathcal{H} = \frac{M}{F} = \frac{M}{\mu d^2}.$$

This property of a portion of a magnetic field by virtue of which a magnetic pole will always be acted upon by a force is called its intensity. The unit of such intensity $\mathcal{H}$ is the dyne per unit pole strength of the exploring magnet and is named the *gauss*.

The application of this theory and its dependent mathematical analyses lead to the following conclusions and corollaries when applied to the fairly simple and uniform dielectric or magnetic fields. The illustrations and units will be taken only from the dielectric cases.

The electric intensity due to a charge uniformly distributed over a spherical surface is zero for all points within the surface, while for all points exterior to the surface the intensity is the same as if all the charge were concentrated at the center of such a sphere. Such an application is of fundamental importance in studying and calculating the fields about sphere-gaps used for high potential measurements and for

similar contours on high-voltage terminals of simple spherical shapes.

For coaxial conducting cylinders, the electric intensity at points exterior to and not too far from the mid-point of a long cylinder uniformly charged is the same as if the charge were uniformly distributed along the axis of the cylinder. This corollary is fundamental in the study of single-conductor cables.

From Gauss' theorem as applied to the simple geometric field there may be obtained a concept of Faraday's so-called tubes of force and the principles of the equipotential surfaces and traces which are so fundamental in portraying stresses in dielectrics. Of the many corollaries derived therefrom, those of greatest practical value are perhaps the following:

(1) The surface of any homogeneous conductor, or group of connected conductors, in an electrostatic field is an equipotential surface.

(2) No work will be done by, or against, the forces of the field in moving a charge around upon an equipotential surface.

(3) The electric intensity at any point upon an equipotential surface is at right angles to the surface. The lines of electric intensity (commonly called the lines of force) cut through an equipotential surface at right angles to the surface.

(4) If a high-voltage field is mapped out in a dielectric by drawing equipotential surfaces at equal intervals of potential, *i.e.* located possibly 1,000 volts apart, then the intensities at different points of the field are inversely proportional to the perpendicular distances between the nearest surfaces. Thus the distance measured perpendicularly between the traces of equipotential surfaces upon a plane are inverse measures of the respective dielectric field intensities in such an area.

(5) Lines of electric intensity can begin only on positive charges and end only on negative charges, but such a line can not spring from and end upon the same (equipotential) conductor.

(6) A tube of unit flux of electric intensity is a tube of such cross-sectional area that the flux (surface integral) of the electric intensity over any diaphragm is unity.

(7) Usually the axial line of the tube and not the tube itself is drawn.

Thus these tubes, their axial lines of force and their corresponding perpendicular equipotential surfaces and lines were conceived by Faraday and depicted mathematically by Gauss for comparatively simple fields. For irregular conductors, however, such as a line wire and a tie wire upon an insulator, a cable terminal, the armature coil of a high-voltage generator, the end turns of a transformer or even a cloud of irregular shape carrying a bound charge, the contour of such equipotential surfaces can be only very roughly drawn so as to conform, in a general way, to such fundamental laws.

If, therefore, it is possible to determine experimentally either the lines of electric intensity of the equipotential surfaces, their counter-part may be readily and fairly accurately drawn and the dielectric stress determinations made by constructing the corresponding quadrature contours.

Methods of artificial representation have been necessarily used for all but the most simple conductors with the familiar formations of mica filings or asbestos particles introduced into a field upon a piece of cardboard or its equivalent. Such were not only subject to the manipulation of the operator, but were necessarily affected in the plane under consideration by the local introduction of the other dielectrics foreign to the original problem.

(The speaker here described two other methods of studying field intensities which were developed at Purdue University. They are given in detail in Bulletin Number 29 of the Purdue Engineering Experiment Station.)

The next interesting divergent path extending into the practical engineering problem from the assumed uniform field between parallel conducting plates when separated by air is that of introducing other dielectrics into the same potential exposure. This is necessarily done for the reason that the ionization and ultimate breakdown of the air takes place at a stress of 31 Kv. per cm. Such a gradient is very readily reached upon transmission lines and in electrical apparatus.

Moreover, the mechanical forces resulting in such an electrostatic field are relatively small if the gradient is limited to that of air. As an illustration, it may be of interest to point out that at the critical gradient for air the maximum force action is:

$$F = \frac{pE^2}{2 \times 10^{14}} = \frac{8.85 \times (31{,}000)^2}{2 \times 10^{14}} = 425.2 \text{ dynes per sq. cm.}$$

This is only sufficient to support a disc of aluminum approximately 63 mills thick from falling, if not otherwise supported. The forces available upon the floating disc of the electrometer constructed at Purdue University was only 0.1854 grams at 179 Kv., at which voltage it was necessary to have the plates nearly 24 inches apart.

It is possible to demonstrate very forcefully to the student with relatively simple apparatus the resultant increase in electric intensity in an otherwise uniform field of air as glass or porcelain is introduced in series therewith, and the automatic movement of a carefully suspended glass plate into the field from without in order to shorten and increase the lines of force may also be clearly visualized.

In studying the phenomena associated with high electric intensities, particularly at various frequencies, a most fascinating field of pioneer research opens up before the engineering student. Little is known about the conditions which exist, particularly in solid dielectrics, at and near the surface of contact with other dielectrics or adjacent conductors.

It is perhaps reasonable to suppose that a porcelain or glass insulator or a sheet of mica or paraffine under normal conditions contains either unpolarized or partially polarized molecules with their axes in all indiscriminate directions with respect to one another. When placed within a uniform electric field some kind of internal elastic shift may be assumed to take place among the electrons and protons within such a dielectric structure, thereby polarizing the previously unpolarized structure or twisting about and partially aligning such polarized structures as previously existed therein.

When a new dielectric is substituted for air, or more cor-

rectly for a vacuum, in such a field and the quantity of electricity which must be transferred from one electrode to another to produce any specified difference of potential between the electrodes is to be measured, it is found that a definite multiple of the original quantity of that required for the vacuum is necessary. Such a multiple, *i.e.* P_g for glass and P_m for mica, is the permittivity of the dielectric involved. It is always the same for the same material and is always greater than unity.

When comparing this phenomenon with its analogy in the magnetic field, it is of interest to point out the fact that the corresponding value of permeability μ of the latter field for iron is several thousand times that of air while in the dielectric field the highest multiples involved in permittivity are of the order of eight or ten. Accordingly, the field intensities or leakages of non-symmetrical fields in the dielectric are rather more important and more difficult to calculate than the leakage magnetic flux in air. Furthermore, in the magnetic analogy there are a few materials having a value less than unity.

To return to our charged conductors separated by some dielectric: Thus far, only the electrostatic conditions have been considered. But suppose we connect the plates by means of a conductor. The charges are neutralized by some kind of a transfer of electricity through the connecting conductor. The nature of the transfer is not yet known. In fact, it is better understood if the discharge takes place through ionized air or other gas than through a solid conductor. We do know, thanks to Faraday, that such a moving charge, or electric current is acted upon in an electric field just as a unit charged particle or electron is affected.

One of the most convincing demonstrations of the similarity between a transfer of charges from point to point throughout a vacuum or gas in an electric field and the action of what is commonly known as the electric current flowing in a conductor in the same field is that of the deflection and control of an electron jet, or cathode-ray, as it is caused to pass between the plates of the condenser. In short, if the student

can understand the transition from the moving current-carrying wire or coil of a motor or meter in an electric or magnetic field, or of the current-carrying loop of the Duddell or Einthoven oscillographs in a magnetic or, better, in an electric field; if he can bridge this mental gap to the control of the electron jet of the cathode-ray oscillograph, either by means of the magnetic or electric field through which it passes, his mind is receptive to the electron theories of advanced electrophysics and to the modern concepts of electrical engineering measurements.

For example, the moving element of the cathode-ray oscillograph, is the electron jet or ray consisting of electrically charged particles possessing an extremely small mass travelling at a very high velocity. Since these particles possess some mass, their rectilinear propagation follows directly from the well-known mechanical principle of inertia. However, since the particles are electrically charged, the electric field has an effect upon them similar to that which the gravitational field of the earth has upon every material body. Therefore, the cathode-ray particles should theoretically describe a path in an electric field which has a form similar to that of the trajectory of a body thrown in the gravitational field of the earth, a parabola. As a fact, the cathode rays do follow this form of curve.

It also follows, without considering the composition of the atom, that a moving, electrically charged mass should describe a circular path in a magnetic field acting at right angles to the direction of motion. Experiment shows that this does occur.

Thus we have a ray, which may be visualized upon the fluorescent screen whose velocity and penetrating power may be controlled by its accelerating voltage impressed between anode and cathode and whose position and movement in an electric or magnetic field may be controlled by varying the magnitude and direction of the controlling field. Since the mass of the electrons and their inertia are both extremely small, their jet may be accurately controlled by means of fields

varying at the extremely high frequencies of the order of millions of alternations per second.

Let us return to the consideration of the simple two-plate condenser charged to a relatively high voltage of definite polarity. This might be thought of as the Leyden jar of the physics lecture room or the lightning surge generator of the high-voltage laboratory. The discharges of all such are dependent for their magnitude and characteristics with respect to time intervals upon the resistance, inductive reactance and capacitance of the discharge circuit. The nature of such a current discharge should be carefully explained to the student and its marked distinction from the normal current flow of the direct-current circuit and the alternating 60 cycle circuit should be thoroughly demonstrated. The average student does not carry over the proper concept from the Leyden jar in his study of physics and does not appreciate the marked distinction until he takes oscillograms in the electrical laboratory of the transient discharges of the condenser and until he calculates the effects of variations of resistance of the discharge circuit upon the damped and oscillatory voltage and current values which result. Although it may not always be possible to introduce an extensive course in transients into the curriculum, one or two laboratory experiments with the oscillograph such as have been outlined by Magnusson in his text on Electrical Transients should now be required; since transients are so commonly met in practice.

The most important and ever-present Ohm's law has already been discussed. Drill upon it in all of its forms should be given until its multitudinous applications are readily recognized. The many aspects in which they may appear to the engineer not only in the better known cases of calculation of resistance and current but in determining potential differences should be used as illustrations. The allowable voltage drop per mile in railway track to limit serious electrolysis, the potential above ground of the neutral of a transmission system resulting from a current discharge through the grounding resistance, the *IR* drop in motors and generators at various loads, the resistance units of the railway or industrial motor

control to provide proper speed regulation, the voltage between portions of a tree or a pole, in which a current leakage to ground exists and the opposition to flow of current in an automobile storage battery are all sources of practical problems which may add interest as well as ingenuity of solution to Ohm's law.

Little has been said thus far, as promised in the introduction to this discussion, regarding the economics of electrical engineering. The best connecting link between Ohm's law and the many of the dollars and cents applications is the all-important Kelvin's law of economic selection. Several exercises may well be spent upon this fundamental principle of all efficient engineering, particularly if the application of the law be broadened to the selection of other equipment than distribution cables.

As this law is frequently and all too narrowly stated, the most economical size of cable is that in which the fixed charges equal the annual cost of I^2R energy lost.

In the broad application of this sound economic principle to all engineering selection it should be stated as follows: That new or additional equipment is best, from an economic standpoint, whose increase of fixed charges over an adequate period of years is equal to the saving in reduced operating costs which may result during such a period.

In following the various paths open to a direct current resulting from a constant potential supply the laws of Kirchoff are found to be excellent auxiliaries to Ohm's law in the solution of network problems. In our attempt to avoid the stereotyped definition so often required to be memorized and with the expectation that a contact with the practical problem procedure is of value, the form is quoted in which these two important Kirchoff's laws are found in the new and excellent textbook entitled "Physics for Colleges" by Sheldon, Kent, Paton and Miller.

> "Kirchoff's first law is merely the statement of the observed fact that electricity flowing through a conductor, or network of conductors, *does not accumulate anywhere.*
>
> "The second law states that if we start at any point in an

> electrical system, containing as many complications as you please, and go on a journey through falls of potential, over electromotive forces, around loops of conductors, anywhere in the circuit but finally get back to the same place we started from, then the sum of rises and falls of potential will be zero. This is obvious since, being back at the starting point, the potential level must be the same."

Practice in solving many complicated network problems by means of Kirchoff's laws developed the following standards of procedure which will assist materially in securing accurate results and in reducing the time required for solution.

(1) All unknown currents must be given an assumed direction.
(2) All known currents must have their directions shown.
(3) In applying the second law, use in every case the smallest possible loop. It is preferable to trace loops in the same direction to avoid mental errors in sign.
(4) Every equation must be independent of every other equation, *i.e.*, every equation set up must contain some new unknown quantity not contained in any previous equation.
(5) The number of junction equations plus the number of loop equations must equal the number of unknown currents.
(6) In order that enough junction equations may be obtained, it is necessary that the junctions be taken in consecutive order around the network.

Having created the electric current as a result of the supply of a potential through the resistance of one or more branched circuits in accordance with Ohm's and Kirchoff's laws, let us analyze its effects and the laws governing such results as may be produced thereby.

First we encounter the heating effect. Since from Ohm's law there was found to be a drop in potential IR, there must be some work done and some energy transformed. Ask the student how he would determine whether all of this which is transformed in the conductor appeared as heat. How would

he proceed if he had never heard of the mechanical equivalent of heat. It seems now a relatively simple matter to propose the measurement of the heat and to compare that with the energy dissipated if expressed in the same units. Thus we have Joule's law of $IR \times I = I^2R$, an important addition to Ohm's law.

If the flow of current produces heat in a conductor, why does not the application of heat to the conductor produce an electromotive force and the resultant current? This is a good question for the more able students to look up and present at the next class period. True it is, of course, that the so-called Peltier, Seebeck and Thompson effects indicate the establishment of an e.m.f. and current under certain conditions and with certain carefully selected conductors but nothing comparable quantitatively to the reverse process in the generation of current has been found.

If an iron wire, forming a closed loop, is heated at one point, the heat will tend to flow equally in both directions from the hot spot. If, however, a source of electrical potential be introduced into the iron wire loop, the heat is found to travel along the wire more readily against the electric current than it is in the direction of the current. The effect is exactly the same as if extra work had to be done to transfer the electricity away from the hot spot with the current than was necessary against it. Such work per unit quantity of electricity may be considered as a measure of a thermal e.m.f. This is the Thompson effect. It has long been known that a hot body will not retain its electrical charge as well as a cold one. Different substances show this effect in varying degrees. But still more important is the well-established fact that a hot body will lose a negative charge more readily and rapidly than a positive charge. In fact, a properly insulated neutral hot body may even acquire a positive charge. This is due to the fact that a hot body, such as the filament of an electric light bulb, will give off electrons much as a liquid will evaporate. Therefore, a small difference of potential applied to the electrodes of a vacuum tube will provide a constant current but such a current will not obey Ohm's law, for

the number of electrons liberated determines the amount of current that flows.

In fact, if an electrode is coated with certain oxides in order that it may give off a relatively great number of electrons when heated, the voltage may be very high before the electrons will be swept away as rapidly as they are formed. In this case, the current flowing through the tube will neither depend directly upon Ohm's law nor upon the temperature of the heated electrode, but upon the three-halves power of the voltage. The law is $I = kE^{\frac{3}{2}}$. Here we have the effect of the so-called "space charge." The electrons, once driven off, unless removed at once from the region of the hot electrode, prevent other electrons from evaporating as a result of their neutral electrostatic repulsion. An atmosphere of electrons in a region from which most of the molecules and atoms have been removed by evacuation, gives rise to strong electrostatic fields in this region known as "space charges."

So much for the more important laws of electrical engineering which may be considered as fundamental. Nothing has been said about the action of electricity in liquids, of the peculiar characteristics of liquid dielectrics, such as oil insulation, or of liquid conductors, such as electrolytes. The problems of electrolysis are legion and of great practical importance. The laws of electrostatic and electromagnetic induction, particularly that attributed to Lenz, which accounts for the continuation of the flow of current as well as the lag in the establishment of such a current in an inductive circuit, have barely been mentioned. Even with those which are well-known included, the list is not a long one and yet our whole civilization now depends upon their action.

Teaching the Fundamental of Electrical Engineering

Upon entering my office recently and tearing off the daily calendar page of the Henry Doherty Fraternity calendar, my attention was particularly attracted to the following very pertinent statement:

> "Probably not more than one pioneering venture out of

twenty pays, and yet nearly all of our progress is dependent upon pioneer work. We fail to appreciate the debt we owe to our pioneers."

Such a statement applies to teaching methods as well as to scientific, economic and industrial development. The teacher and institution that fail to blaze new trails as the result of new pedagogical experiments soon find themselves in a rut which, in accordance with the old adage, is likely to "widen into a grave."

Much pioneer experimentation and the subsequent adoption of improved teaching methods have been the result of the initiative and inspiration of the S. P. E. E. and particularly of its Board of Investigation and Coordination. The problems of and the contacts with industry and its needs which have been uncovered by the survey of this Board have been of great mutual advantage. The institution, and particularly the school of electrical engineering, that does not take advantage of such development work will soon find itself in the background of educational progress.

Since this is supposed to be an informal experience meeting, some of the new projects which are being tried out at each institution here represented may well be discussed. With that in view, some of the more important methods, new to us, but possibly old to other institutions will be suggested.

We believe thoroughly in the concentric method as an ideal which should be approached as closely as practicable. Nothing so thoroughly and so interestingly holds the attention of the student and creates the determination to know the reason for a result as some unique and, perchance, spectacular demonstration of a new machine at the beginning of a laboratory period with the only instructions given to the student—*"find out what caused it and report."* All of the carefully expounded theories and the well-planted tests and problems which can be devised by the ingenious instructor fall short of the equivalent of connecting a 60-cycle transformer to a 25-cycle circuit to "see what it will do." *Possibly a direct current supply might be tried as well!* Certain laws have been indelibly fixed in my mind as the result of practical expe-

riences which, unfortunately, came long after graduation. I wish the equivalent might be provided for the student in college today. We must approximate this as closely as possible without incurring too great risk of accident.

Those of us who still have visions of experiences on the test floor of motors running away due to an open field, the shutting down of a power plant or converter due to a poor job of synchronizing, or the electrocution of a test buddy upon the "inductive kick" of an open field switch or the breakdown of transformer insulation due to overload and carbonization have insisted upon knowing the "reason why!"

Of course, we would not reproduce such conditions in the laboratory if it were possible. However, I still maintain that the more nearly the administration of instruction, particularly in the laboratory, can approach those practical conditions which the student will have to face after graduation, the better, the more economically advantageous, and the more lasting will be his engineering education.

To this end, we have retained the thesis and, insofar as possible, the experimental thesis as a requirement in spite of its difficulty and its extra cost. Nothing that we can do seems to approximate so closely to the ideal concentric method of instruction nor so effectively places the responsibility for the *"what"* and *"why"* and *"how much will it cost"* upon the student as does the thesis. A few of the most satisfactory theses of this type are given in the following table:

TYPICAL THESIS SUBJECTS

Purdue University

1927–1928

The Study of Iron Losses in Modern Transformer Cores.
Experimental Investigation of Electrical Resistance at Temperature of Liquid Air.
Study and Report upon Recent Decisions of Public Utility Commissions.
Transmission of Single-Phase Power between the Neutrals of a Three-Phase System.
Calibration and Development Study of a Noise-Measuring Apparatus.
A Study of Four-Element Vacuum Tubes.

Analysis of Central Station Distribution Loads and Their Probable Future Demands.

Design, Construction and Test of an Oil Insulated High Frequency Oscillator.

Algebraic Wheatstone Bridge for Solution of Equations.

Tests on Artificial Transmission Line at Audio Frequencies.

Performance Test of 50,000 kw. Turbo-Alternator.

A Study of Railway Car Truck Mechanics.

Model Representation of Vector Loci Along Transmission Lines.

Comparison of Auto Transformer and Primary Resistance Methods of Starting Induction Motors.

Study of Electric Filters.

Determination of Short Circuit Currents in Transmission Networks by the Use of a Short Circuit Test Board.

Design, Construction and Test of a One-Way Carrier Telephone System.

Determination of the Electrical Resistance and Other Physiological Properties of the Human Body.

Magnetic Properties of Iron at High Temperatures.

Design, Construction and Test of Short Wave Radio Telegraph Transmitter.

Demonstration Model of a Rotating Magnetic Field.

Impulse Tests on Solid Dielectric.

Design, Construction and Test of a KVA Meter (Green Principle).

Design and Construction of a Hot-Wire A. C.–D. C. Comparison Instrument.

Electrical Public Utility Holding Companies and Their Regulation.

An Oscillograph Study of Steady and Transient Conditions in Electric Circuits.

Design, Construction and Test of Portable Cathode-Ray Oscillograph for Communication Frequencies.

Nature of Electrical Breakdown of Solid Insulation.

The Design and Construction of a Constant Frequency Control.

Analysis of Rail Corrugation Data.

Design and Performance Characteristics of a Special High-Speed A. C. Generator.

Vector Model of a Transmission Line.

A Study of Internal Temperatures in Wire Coils.

Comparison of Types of Rate Schedules and Their Resulting Gross Revenues.

An Analysis of the Traffic Studies which Have Been Made in Lafayette.

A Study to Determine the Advisability of Standardizing on 10 Ampere Watt-hour Meters for all Loads up to 25 A.

The previous statement regarding the desirability of making laboratory conditions as nearly true to practice as possible warrants the suggestion that live equipment, dangerous to life, should not be avoided in the laboratory nor should the safety devices provided therewith be abnormal in number nor in type. While the administration justly feels some responsibility for the safety of students, it should bear in mind its responsibility to its alumni and their subordinates who must work with and take responsibility for dangerous circuits in the future. We are of the opinion that the electrical engineering laboratory administrations—and, unfortunately, there are many such, in which the students are neither able nor allowed to handle high voltages—are shirking their real duty in this respect.

The next best approximation to the concentric method of instruction seems to be that of limiting the number of subjects and instructors per student to a minimum. It is impractical, of course, to provide equipment which may be retained by one group of students to disassemble and test to destruction, if necessary, to carry out this method fully. However, the equipment which is being studied in both classroom and laboratory may be and is limited in this plan. Its slogan is "*One subject; i.e.,* machine or circuit, *one and the same instructor* (in both classroom and laboratory) *for one group of students.*" There is no distinction between laboratory assignment and classroom assignment until the subject at hand is finished; then both change simultaneously. A recitation period may be a preparation for, or a review of, a laboratory period, or it may provide text-book or lecture theory upon the same subject. There are no separate requirements nor grades; it is one concentrated course under one instructor.

Last year, another new plan was undertaken throughout the entire university of establishing the *minimum essentials* of each course in the form of an outline of requirements for credit. This was the natural development following a new grading system in which numerical grades were abandoned. The student who demonstrated in all portions of the work

such as: laboratory exercises, reports, classroom tests, final examinations, etc., that he knew the minimum essentials received a passing grade of P. Those who did not measure up to this requirement might receive a "condition grade of C" which, in the opinion of the instructor, might be made up by a condition examination; or the student might have a D grade and be required to repeat the course.

In addition, other more advanced requirements, both qualitative and quantitative, were stipulated for the students with more ambition and better background. Such students may attempt more work upon the same general assignment, may perform more allied tests in the laboratory, look up and present in class abstracts from affiliated references from the library, etc., for additional credit. For such students grades of B, A and H (the latter an honor grade) are available and are so established as to be sought after by the more able students, not as a grade alone, but because of the additional knowledge required to earn it. Furthermore, a certain percentage of all the grades (90 semester-hours in the four years) must be "B" or higher.

Although, of course, not unanimously recognized by all instructors as a step in advance, this combined system of (1) definite outlines of minimum essentials of each course, and (2) a grading system free from the objectionable decimal or percentage average, has been favorably received for the following reasons, which are listed approximately in their order of merit:

(1) It provides a clear-cut statement of the content and requirements of each course.

(2) As a result of (1), the prerequisite and dependent courses may be more readily and adequately correlated, particularly as the student passes from one department to another.

(3) It stamps more definitely upon a student his status in the sequence of courses and his progress from week to week upon the outline for the term.

(4) It provides for the full activities and application

of the more able students of the class without the necessity of sectionalizing in proportion to ability.

(5) As a result of (4), the poorer students are assisted by the contributions of their more able classmates and the affiliated illustrative matter and problems of the subject under consideration are not neglected; nor do they require large amounts of time on the part of all students, many of whom are unable to study all references and perform all problems.

As an example of the minimum essentials of the four fundamental courses, known as Electrical Engineering 5, 6, 7 and 8, which are undertaken in the two junior and two senior semesters after the elementary freshman orientation work and the sophomore prerequisites and laboratory experience, the accompanying outlines are submitted. These do not include several other *required courses* in electrical engineering subject, nor do they cover any of the so-called *application* or *technical elective* courses.

Minimum Essentials

Electrical Engineering 5

The student must satisfy the instructor of his knowledge and ability concerning the *theory* and *calculation* of each of the following items:

General:

1. Electron theory of conductor and insulator.
2. Electrical, mechanical and heat energy equivalent.

The Electric Circuit:

3. Joules Law.
4. Ohms Law in simple circuits.
5. Ohms Law and Kirkoff's Law in electrical networks.
6. Equivalent networks.
7. Insulation and insulation resistance.
8. Distribution circuits.

Electrical Resistance:

9. Laws and units of.
10. Conductors of uniform and non-uniform section.

11. Temperature effects.
12. Per cent conductivity.

Wire Tables:

13. Basis of Brown and Sharpe tables.
14. Exact and approximate relations between sizes.

Electromagnetism:

15. Definitions of fundamental units and statement of fundamental experimental laws.
16. Basic definition of unit current.
17. Magnetic fields produced by straight conductors, circular loops, solenoids, and other circuits.
18. Force reaction between circuits.
19. Electromagnetic generation of e.m.f.
20. Work of conductor in magnetic field.
21. Magneto motive force.
22. Permeability and reluctance.
23. The magnetic circuit.
24. Magnetism in iron.
25. Energy stored in magnetic fields.
26. Hysteresis in iron.
27. Pull of magnets.

Inductive Circuits:

28. Units of inductance.
29. Self-induction.
30. Mutual induction.
31. Effects of self-induction upon changes of current strength.

Principles of Meters:

32. Indicating meters, watthours, megger and oscillograph.
33. Shunts and multipliers.
34. Damping.

Direct Current Generator:

35. Structural details and functions of the various parts.
36. Calculations of magnetic circuit, magnetization curve, field and armature windings.
37. Generation of electromotive force.
38. Rectification and commutation.
39. Armature reaction.
40. Characteristics of operation, as saturation curves and load curves.

41. Compound and shunt generators.
42. Parallel operation.

Electrical Engineering 6

The student must be able to

Direct Current Motor:

1. Compute torque of a direct current motor from constants and specified conditions.
2. Compute speed, regulation, or current of a direct current motor from specified load and constants.
3. Design the resistances for a starting box for a motor.
4. Specify suitable motor for given specified service and duty.
5. Make measurements and computations necessary in obtaining stray power.
6. Make necessary measurements and computations for efficiency of a direct current generator or motor.
7. From constants of machine compute its maximum efficiency.

Alternating Current Circuits:

8. Compute effective value of alternating current for any specified wave form.

8a. From ordinator of a given wave ascertain magnitude and phase relation of fundamental and harmonics.

9. Develop power equation for alternating current circuits.
10. Compute power factor of an a. c. circuit from circuit constants or other specified conditions.
11. From given constants and voltage compute current in any a. c. circuit.

11a. Make general solution of Helmholtz's equation for circuit with inductance, resistance and capacity when *variable* e.m.f. is applied.

12. From circuit constants compute frequency producing resonance for either series or parallel circuits.
13. Express alternating currents, voltages or impedances as vectors or in any of the various symbolic forms; transform them from one form into any of the others; and make computations of these quantities using any of the foregoing systems of representation.
14. From circuit specifications compute apparent power, reactive power and real power.
15. Apply Kirchoff's Laws to the solution of any polyphase network, particularly three-phase networks.
16. Make measurements in three-phase networks to determine phase sequence.

17. Compute power in a polyphase network from specified conditions and constants.
18. Measure power in a three-phase network by various available methods.

Electrostatic Circuit:

19. From the specifications of dimensions and materials, to compute electrostatic capacity of parallel plates, spheres parallel conductors, or of a cable.
20. From the specifications of dimensions and voltage conditions to compute the electric stress at any point in a dielectric between parallel plates, between parallel wires, or between conductor and sheath of a cable.
21. From the specifications of dimensions and material of the dielectric to predict probable voltage to cause breakdown.

In addition to the foregoing satisfactory completion of experimental work and written report on fifteen assigned projects is required.

ELECTRICAL ENGINEERING 7

The student must have an accurate working knowledge of

Transformers:

1. The general construction details of transformers.
2. The inter-relations of the voltage, flux, frequency and turns of a transformer.
3. The laws relating to the magnetic circuit of the transformer, including the law of ampere turns.
4. The complete vector diagram of the transformer.
5. The test data necessary to determine transformer performance and the test methods involved in the determination of these data.
6. The calculation of the regulation of a transformer.
7. The calculation of the losses and the efficiency of a transformer.
8. Various transformer connections, including the auto transformer and polyphase transformation.
9. The more common transformer applications.

Induction Motors:

10. The production of the revolving magnetic field in polyphase motors.
11. The windings used on induction motors.
12. The construction details of induction motors.
13. The inter-relations of rotor current, rotor voltage, rotor speed, and rotor constants.
14. The torque and power relations of the induction motor.

15. The induction motor circle diagram, the data necessary for its construction and the test methods involved in the determination of these data.
16. Induction motor performance under varying conditions of load, voltage and frequency.
17. The more familiar induction motor applications

Alternators:

18. The construction details of an alternator.
19. Alternator windings.
20. The open-circuit and short-circuit saturation curves of an alternator, and the test methods used in their determination.
21. The calculation of the regulation of an alternator.
22. The measurement of the losses and calculation of the losses and efficiency of an alternator.
23. Alternator performance under different conditions of load, load power factor, excitation and speed.
24. The parallel operation of alternators; synchronizing, division of load, etc.

Synchronous Motors:

25. The construction details of the synchronous motor.
26. The production of torque in the synchronous motor.
27. The effect of changes in load and excitation in the performance of the synchronous motor.
28. The construction of the circle diagrams of the synchronous motor and the test data necessary for these constructions.
29. Common synchronous motor applications.

ELECTRICAL ENGINEERING 8

The student must be able to solve problems, both in the laboratory and in the class room, involving the minimum requirements for Electrical Engineering 5, Electrical Engineering 6 and Electrical Engineering 7, and, in addition, be able to solve the more common problems relating to:

1. Synchronous Converters.
2. Rectifiers.
3. Meter Connections.
4. Power Transmission.
5. General Engineering Applications.

Much is being done to encourage the distinguished student; the student who, during the previous semester, has to his credit 75 per cent A or H grades (the two highest grades)

and no conditions or failures. Up to the present time such a student has been granted many special privileges, such as irregular schedules, taking two subjects with partially conflicting hours, absenting himself from class upon previous arrangement with his instructor, special recognition at graduation, etc. Most of these privileges have not been abused, for one cannot abuse them to any marked extent and maintain his distinguished rating. In general, this is an experiment considered to be well worth the undertaking.

Next year an additional, and much more sought after, privilege is being provided for able students through the rebating of certain fees during each semester in which the high standing is maintained.

Within the very general rules and policies of the university as a whole and the college of engineering in particular, the school or department of electrical engineering may inaugurate many unique and well worth while teaching projects as the result of the initiative of some instructor who may propose and demonstrate at a weekly staff meeting the merit of such a new plan. If found sufficiently meritorious, they will receive, after careful consideration, a majority or preferably a unanimous vote.

Furthermore, the individual instructor is able in most institutions to try out in the administration of his particular course many experiments in teaching without interfering with the rules of the department or university but with a rather prompt reaction, either positive or negative, from students and other members of the staff. Such experiences are usually worth while if they are not carried on too frequently or at the expense of the quality and quantity of instruction.

In conclusion, it may not be out of place to summarize an ideal goal to be sought which may be outlined something after this fashion:

(1) The requirements or *minimum essentials*, expressed qualitatively and quantitatively, for the average student of the class are outlined and placed in the hands of all students at the beginning of the semester.

(2) All of the requirements of the course and individual

section with respect to routine procedure, use of text, reports, abstracts, treatment of absences, grades, etc., should be outlined in a talk at the opening of the course, particularly if the instructor is meeting a new group of students for the first time. More difficulty arises from a lack of thorough initial understanding of the requirements in a particular section than from any other one cause.

(3) The instructor must as soon as possible fix every student in his mind in order that his face immediately enables the name to be called and vice versa. His background and previous record should be studied. The informality of the classroom, with the elimination of the roll-call and records, is greatly to be urged.

(4) As soon as his capabilities are known to some extent, each student should be expected to volunteer for or should be assigned outside work or extra references or problems in proportion to his ability for the benefit of the others in the class.

(5) No educational training is worth while unless it can be adequately expressed in good oral and written English. Those not able to abstract references and prepare reports satisfactorily should be referred back to the Department of English for further training.

(6) The review at the beginning of the period, the problem of the day and, to some extent, for the more able students, the outline for the next period, should be as nearly a voluntary and informal discussion as possible. Those who do not volunteer in the discussion must take the consequences of mediocre knowledge. The instructor who cannot read the student and determine what he knows about the subject without formal recitation, should secure another position. He may be able to lecture but he cannot teach.

(7) Each period, insofar as possible, should include the following program:

(*a*) Review of last period.
(*b*) Practical application of last principles with brief economic application.

(*c*) Discussion of present assignment or topic with outside references presented by one or two of the more able students as advanced assignments.

(*d*) Correlation by instructor of present discussion with review subject, laboratory test and subject to be considered at next period.

(*e*) Discussion of test results, errors, curves, etc.

(*f*) Practical application and illustrative problem.

(*g*) Outline of next subject by instructor or able student of the section.

(*h*) Impression gained during the period of knowledge of subject and initiative of each student should be jotted down briefly by instructor immediately following class adjournment.

Such is the problem of the ideal instructor as he conducts the ideal instruction period.

We have all kinds and conditions of students before us in spite of the sifting process which each has been passing through for the past fifteen years. They all have some good qualities and we must discover and develop them. That is our job.

THE TEACHING OF THE FUNDAMENTALS OF ELECTRODYNAMICS

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The Problem of Electrodynamics. In this discussion, the term *electrodynamics* is being used in the sense indicated by the position of *dynamics* in the following classification of the divisions of *mechanics*.

Mechanics: treating of the motions and deformations of bodies.

I. Kinematics: dealing with the classification and description of motions.

II. Dynamics: dealing with the causes (circumstances) of change in condition of rest and motion.
1. Statics.
2. Kinetics.

That is to say, electrodynamics treats of the electrical circumstances associated with motions and deformations.

Perhaps the best approach to the question *"What are the fundamentals of electrodynamics?"* is to be made by first raising an underlying question which can be answered more concisely; namely, "What is the *problem* of physical science, of which electrodynamics is but a branch?" To me, the most direct and significant answer to this question is contained in the statement that *the problem of physical science is to devise the simplest and most comprehensive account of observed motions and deformations.*

This answer is an extension of the range of Kirchhoff's statement of the problem of mechanics. The statement may well serve as the common thesis which all texts on physical fundamentals are expected to sustain and illustrate. It may serve as the touchstone, or at least serve to furnish the clue to the touchstone or the criteria, by which the soundness of the foundations and of the teaching of the fundamentals may be judged.

In the light of this statement of the problem of physical science, we may say of electrodynamics that it deals with the development and trial of the electrical concepts which have been devised for the purpose of rendering a simple account of observed motions and deformations.

The Criteria of Sound Method. It would seem that we may then set up statements such as the following as criteria by which to pass upon the merits of any presentation of electrodynamics.

a. To the extent to which any presentation of electrodynamic theory and electrodynamic relations emphasizes and keeps prominently in the foreground the facts of primary observation, to that extent it is dealing with the fundamentals of experience. These facts of primary observation are

selected features of the great complex of motions which the theory has been devised to account for and to correlate.

b. The meanings of electrodynamic concepts are contained in the experiences which the thinker has undergone, or conceives that he will undergo, in performing the sets of operations in terms of which the concepts are set apart. The fundamental meanings of the electrical quantities are to be sought in the movements of the measuring operations with scale, balance, and time-keeper which must be carried out in the process of assigning numerical values to the quantities. Consequently experience in the laboratory for the student plays a very essential role in the teaching of the fundamentals.

c. To the extent to which a text or a treatment of electrodynamics slurs over or obscures the observations upon which its concepts are based by substituting a dogmatic presentation of concepts for an inductive development of the relations between the observations, to that extent it opens the way to the idolatrous tendency to think entirely in terms of the symbols or the scheme which has been invented for convenience in description, and to think not at all in terms of the things or the experiences symbolized.

d. The prevailing misuse of such notions as that of lines of electric and magnetic intensity is a glaring example of the rather universal tendency to ignore or to forget the origins and to deal with any *construct* of the imagination to which a name has been given, as if it had a physical existence. The effect of "idolizing" lines of intensity is to divert the thought from the fundamental things—from the things which can be actually measured, namely, the forces on bodies, to a scheme which has been invented for convenience in describing the forces. When such a diversion occurs, the symbol or the image becomes the primary object of consideration, and thought tends to take the form of unbridled speculation having a very remote connection with reality. A sound presentation of fundamentals requires a critical attitude toward careless and misleading forms of expression, and it calls for the cultivation of the habit of precision in defining and using technical terms.

e. Learning has been characterized as a concentric process in which the individual, in his first consideration of any new and difficult field, obtains only vague, inadequate, and perhaps partly erroneous ideas. Each subsequent experience in the field serves to correct and build up the first ideas. It follows that the teaching process must to some extent be a concentric process. Herein lies the difficult problem in the first presentation of electrodynamics, namely, to pursue a happy medium between a course which fails because it contains too much for which the student is not prepared and a course which fails because it is elementary in the sense that it is loose and superficial. Since first habits of thought are so hard to supplant, it is a matter of vital concern that the introductory presentation of electrodynamics shall not result in a faulty and disjointed foundation.

f. A course in electrodynamics for engineering students should be made motivating by the early and frequent use of exercises which show the important engineering applications of electrodynamic principles and relations.

g. Finally the presentation of electrodynamics should include sufficient history of the evolution of its concepts to quicken and foster that precious thing—the spirit of critical inquiry into the validity, adequacy and limitations of accepted concepts and principles.

Sketch of the Features of a Course in Electrodynamics for Electrical Engineers. The typical electrical engineering curriculum in this country has among its requirements a course in general physics, to which some 10 or 12 semester hours are allotted, and required studies in electric circuits and machinery to the extent of 24 to 36 semester hours. In the 10 or 12 credit course in general physics, it is only possible to devote some 3 to 5 hours to the study of electrical theory, and it necessarily follows that the theory presented in such a course is somewhat sketchy.

When the electrical students begin the studies given in the electrical departments, it seems to be very generally assumed that they have already had an adequate inductive develop-

ment of general electrodynamic theory. At least this is to be inferred from the fact that the typical texts used in the beginning electrical studies, and in the studies which follow, devote scant attention to the development of underlying principles. In those texts, the laws are stated rather abruptly and their applications to circuits and machines are then considered. Partly as a result of this experience, the average graduate in electrical engineering has a knowledge of electrodynamic theory which is not reasonably unified and correlated.

As an illustration of the lack of correlation, the situation relative to the presentation of two laws which are basic in the generation and utilization of electric power may be cited. The current teaching practice is to develop the law for the *mechanical force* which acts on the conductors in the magnetic fields of electric motors, thereby causing rotation, and the law for the *electromotive force* which is developed in the conductors moving in the magnetic fields of generators, as two independent and unrelated laws. Possibly 80 per cent of the men who graduate in electrical engineering regard these relations as quite independent relations. And yet these two phenomena—the mechanical force on the wires of the motor and the driving force on the electricity in the moving wires of the generator—are but different aspects of the force which moving electrons experience in a magnetic field. The two formulas or laws are to be viewed and treated, not as independent unrelated laws, but as special forms of a more general and all inclusive law.

In the time at my disposal I propose to sketch some of the features and exercises of a course in electrodynamics which have been worked out in the attempt to better the situation presented above. The course in question is intended as an introductory course in electrodynamic theory for students in electrical engineering. As we have given the course, it starts at the opening of the second semester of the Sophomore year and continues for one and one-half semesters with three recitation periods, one two-hour computation period, and one three-hour laboratory period per week, or a total of nine semester credits. The course starts when the student has

completed the first semester of calculus and is entering upon the second. One of the aims in starting the course before the completion of the calculus is to strengthen the work in calculus by giving the student object lessons in the engineering applications of the calculus to laboratory situations. The course is intended to start after the student has been over the topics mechanics and properties of solids, liquids, and gases in the freshman or sophomore course in physics.

Some of the distinctive features of the course are as follows:

a. The interpretative discussions are carried on in terms of the forces on electric charge. This makes it possible to correlate seemingly diverse phenomena, and to show that the seemingly diverse formulas relating to these phenomena are but alternative and restricted ways of writing the more fundamental equations expressing the force on electrons.

b. The sequence followed is to consider the forces between stationary charges, then the various forces which produce or oppose the motion of charges in electric circuits, then the forces which constitute the magnetic effects in steady fields, and finally the accelerating forces in non-steady fields.

c. The magnetic pole concept is eliminated from the theory of magnetism except as an alternative means of making calculations in a few special cases. The fictitious character of the set of forces assumed to act on magnetic poles *along* the lines of magnetic intensity is emphasized.

d. The entire treatment of electric and magnetic theory is given in terms of a single system of units, instead of in a mixture of three systems. This system, the Rationalized Practical System, or the ampere-ohm-volt-joule-watt-weber system, has been freed of the irrational 4π factors and the great number of troublesome conversion factors by three expedients:

First: By using the ampere-turn and the ampere-turn per cm. as the units of magnetomotive force and of magnetic intensity.

Second: By using the weber and the weber per sq. cm. as the units of magnetic flux and of flux density.

Third: By assigning to the permittivity p_0 of free space such a value that the electrostatic force between charges is expressed by the formula

$$f \text{ (dyne-sevens)} = \frac{q_1 q_2}{4\pi p l^2} \quad \begin{matrix} \text{(coulombs)} \\ \text{(cm.)} \end{matrix}$$

e. The relations between the units (electric and magnetic) are developed in a systematic *unbroken* sequence, in which each new unit is defined in terms of one, or at most two, of the previously defined units and of the units of mechanics, mainly the quantities of length, force and time. The starting point for this development is the electrostatically defined unit charge—the coulomb.

f. A great deal of stress is laid on the importance of distinguishing between the four types of relations appearing in electrodynamic theory, namely:

1. *Definitions:* Relations which are matters of *definition.*
2. *Experimentally Determined Relations:* Relations which have been determined purely by observation and *experiment.*
3. *Deductions:* Relations which have been *deduced* from fundamental experimental relations for the values of newly defined quantities.
4. *Generalizations:* Relations which are *generalizations* embodying and based upon general experience or upon extended experimental evidence.

g. The student is not called upon to use such electrical measuring instruments as voltmeters, ammeters, and volt-second meters until he has calibrated an instrument of the type in question by an absolute method in which he starts with the definition of the unit and uses no measuring instruments other than a centimeter scale, a time keeper and a set of weights.

A Sketch of the Sequence of the Topics, Experiments, and Quantitative Definitions in a Course in Electrodynamics for Electrical Engineers. In the following sketch,

the sequence of the topics will be indicated mainly by defining the electrical quantities in an orderly, unbroken sequence, and by directing attention to the features of certain of the experiments. The instruction sheets relative to these experiments are contained in the laboratory manuals entitled "Experiments in Electrodynamics."

Motivating and Concept Evoking Experiments. We start to build the theory of electrical phenomena by observing the extraordinary force of attraction for light bodies displayed by materials like glass and rubber which have been rubbed with silk, fur, or flannel. This property was first noted in the case of amber (the Greek *elektron*) and so when Gilbert described his studies of the phenomena he coined the terms *electrify* and *electricity* and defined these terms by saying that a body which has acquired the amber-like property of attracting light bodies is *electrified* or *charged with electricity.*

Thus the primary meaning or the primary attribute of electricity is the display of extraordinary forces.

(The speaker then described the first experiment of the course. This is conducted with a Faraday cage and is intended to call attention to manifestation of the "extraordinary" forces above mentioned, and to their engineering significance. He also mentioned the second test which is the Faraday ice-pail experiment and described the third which is made by use of electrostatic generators of the induction type and is intended to acquaint the student with forces between charged bodies.)

First Quantitative Experiment. We now pass from these qualitative observations and experiments to a consideration of quantitative relations. Coulomb is generally credited with the discovery of the law for the force between charged bodies as the result of measurements made with his torsion balance. In the first presentation of this law of force we accept measurements with the torsion balance as the experimental evidence for the law that

The force of repulsion between two charged bodies in an extended homogeneous medium, far apart as compared with their dimensions, is directed along the line connecting the centers of the bodies, and is directly proportional to the product of their charges and inversely proportional to the square of the distance r between their centers.

This law may be written in the symbolic form

$$f = \frac{Q_1 Q_2}{kr^2},$$

in which the value of the proportionality constant k will depend upon units which may be arbitrarily selected to measure force, length, and quantity of electricity.

If we are not arbitrary in selecting units, but agree to define what we will call the E.S. unit quantity of electricity as that quantity which will repel an equal quantity when placed at a distance of one centimeter with a force of one dyne, then the formula for the force becomes

$$f \text{ (dynes)} = \frac{Q_1 Q_2}{r^2} \frac{\text{(E.S. Units)}}{\text{(cm.)}}.$$

From this definition of the E.S. unit of electricity, a complete system of electrical units was derived. The units of this system were found to be of the wrong order of magnitude for expressing the currents and electromotive forces obtained from batteries and dynamos. To meet the needs of every-day practice, a committee of the British Association recommended the adoption of a unit of resistance and a unit of voltage which were defined to be multiples of the corresponding electromagnetic units by certain integral powers of 10. These two units were defined in such a way that the unit of work became the joule or erg-seven and not the erg. The system of units based on these recommendations is the so-called practical system which has been legalized throughout the civilized world by governmental actions.

For our purpose in basing a derived set of units upon the unit quantity of electricity, the recommendations of the B.A.

Committee are equivalent to saying that we will base the system of practical units on a unit quantity of electricity which is 3×10^9 times as large as the E.S. unit, and we will call this practical unit of charge the *coulomb*. Accordingly, the law of force when written in terms of the practical units becomes

$$f \text{ (dyne-sevens)} = \frac{9 \times 10^{11}\, Q_1 Q_2 \text{ (coulombs)}}{r^2 \text{ (cm.)}}.$$

At this point we make this statement to our students. For the purpose of getting many of the formulas of every-day engineering application which will be derived from the force formula in a more elegant form, let us agree to write the inverse square law in the form

$$f \text{ (dyne-sevens)} = \frac{Q_1 Q_2 \text{ (coulombs)}}{4\pi p r^2 \text{ (cm.)}},$$

in which

$$\frac{1}{4\pi p} \text{ must equal } 9 \times 10^{11}$$

or

$$p \text{ must equal } 8.85 \times 10^{-14}.$$

We agree to call the constant p the *permittivity* of the medium in which the charged bodies are located. We point out that during the course of the next two weeks the student will have occasion to derive formulas from the force formula which will give him some indication of the advantage of placing the factor 4π in the force formula.

In the manner described above the first electrical quantity, namely, *quantity of electricity,* is so defined that numerical values may be assigned to it. The experimental procedure by which the charge in a condenser may be measured will become clear when the experiments are described.

Electric Intensity. The second electrical quantity is introduced to facilitate the description and the specification of the forces which will act upon charges in an electric field.

The term *electric intensity at a point* in a field is introduced and is defined thus:

The electric intensity at a point P in an electric field is de-

fined to be a vector quantity F whose direction and magnitude are the same as the direction and magnitude of the force which the original distribution of charges giving rise to the field would exert on a unit positive charge if it were placed at the point P.

The defining formula for electric intensity is

$$\vec{F} \text{ (dyne-sevens per coulomb)} = \frac{\vec{f}}{Q_t} \begin{matrix}\text{(dyne-sevens).} \\ \text{(coulombs)}\end{matrix}$$

The physically significant name of the unit of intensity is the *dyne-seven per coulomb*. Of course it is well known to this group that the name applied to the unit of intensity is the *volt per centimeter*, but at this stage in the first development of relations this name can have no significance to the student and we strongly insist that the student use the physically significant name, the dyne-seven per coulomb, until he is in a position to understand the significance of the volt per centimeter.

(The speaker here described methods of deducing formulas for computing electrical intensities in special cases.)

Electric Potential. The third electrical quantity is introduced to facilitate the specification of the work which will be done when a charge moves from one point to another under the forces of an electrostatic field. After demonstrating that, in a field of centrally directed forces having spherically symmetrical properties, the work done in moving a body from point A to point B is independent of the path taken by the body, the terms *potential at a point* and *potential increase from A to B* are introduced and defined thus:

The POTENTIAL INCREASE ALONG A PATH FROM A POINT A TO A POINT B is defined to be equal to the algebraic value of work which would be done AGAINST the electrostatic forces due to the original distribution of charges giving rise to the field in moving a unit positive charge from A to B along the path.

The defining formula for potential increase is

$$\Delta E \begin{matrix}\text{(joules per coulomb)} \\ \text{or} \\ \text{(volts)}\end{matrix} = \frac{W}{Q_t} = \frac{-\int f \cos(f, l) dl}{Q_t} \begin{matrix}\text{(joules)} \\ \text{(coulombs)}\end{matrix}.$$

The physically significant name of the unit of potential increase is the joule per coulomb, and the student is encouraged to use this name in his first calculations and then to use the short name which has been coined and awarded by decree to the unit of potential increase, namely, the volt.

(The speaker then discussed the derivation of the general relation between electrostatic intensity at a point and potential.)

Quantitative Experiments. The fourth experiment, coming in the fourth week of the course, deals with the method of starting with the definition of potential difference between two bodies and of devising an absolute method based on this definition of calibrating voltmeters. In the laboratory the student examines the construction of absolute or guard-ring electrometers and then, starting with the inverse square law as expressed in practical units, goes through the integrating operations necessary to derive the formula for the pull on the suspended disc in terms of the charge on the disc and for the potential difference between the discs in terms of the charge. He then eliminates the charge between these two equations and obtains an expression for the pull on the suspended disc in terms of the potential difference between the discs of the electrometer. The absolute electrometer is then connected in parallel with a Weston 1,500-volt permanent magnet voltmeter and a number of points on the scale of the Weston voltmeter are calibrated.

(The speaker then described the fifth experiment in the course which is a quantitative experiment of the motivating type intended to show the application of the inverse square law to the problem of predictions relating to inductive interference between power and telephone lines.)

Capacitance. The next electrical quantity introduced is capacitance. The observation is made that if we have two insulated conductors and transfer electricity from one to the other, the ratio of the quantity of electricity transferred to the resulting potential difference is constant. This straight line relation may be deduced from the fact that the principle

of linear superposition applies to the forces exerted by electric charge. The proportionality constant between the quantity of electricity transferred from one conductor to another and the resulting potential difference is called the *capacitance* of the conductors relative to each other. Thus the defining equation for capacitance is

$$\text{C (coulombs per volt)} = \frac{Q \text{ (coulombs)}}{E \quad \text{(volts)}}$$

$$\text{or}$$

$$\text{(farads)}$$

and the physically significant name of the unit is the *coulomb per volt*, while the short name coined and awarded by decree to the unit is the *farad*.

Electric Current. We next pass to a consideration of the phenomena which occur when electricity flows in a conductor. If the two conductors of an electrostatic generator are connected, various phenomena attend the passage of charge through the conductor, or, as we say, attend the current in the conductor. The passage of electricity is accompanied by (1) a heating of the conductor, (2) a decomposition of suitable solutions, (3) by forces of attraction or repulsion between portions of the wire and on nearby pieces of iron. Electric current may be defined by any one of these effects. Thus, unit current might be defined to be the current which, flowing in a long straight wire parallel to another wire carrying the same current, attracts it with an arbitrarily chosen force per unit length, or unit current might be defined to be the current which deposits copper from solution at an arbitrarily specified rate, but the unit current if thus defined would be an arbitrarily chosen unit not based in any way on the electrical quantities previously studied and defined. On the other hand, if the current is defined thus:

> The value of the current in a specified direction in a wire is defined to be the algebraic value of the equivalent time-rate of passage of positive electricity in the specified direction across a section of the wire,

such a unit of current is a unit derived from previously de-

fined electrical quantities and the defining equation for a current becomes

$$I \text{ (coulombs per sec.)} = \frac{Q \text{ (coulombs)}}{t \text{ (sec.)}}.$$
$$\text{or}$$
$$\text{(amperes)}$$

Here again the name applied to the unit is not the physically significant name, the *coulomb per second,* but a short name which has been coined and awarded by decree, namely, the *ampere.*

The sixth experiment of the course, coming in the sixth week, is intended to show how to use this definition of unit current as the basis for an absolute method of calibrating meters to read in amperes. It is also intended to enable the student to determine the value of the gram-equivalent of the coulomb; that is, the value of the universal natural constant k in Faraday's law, namely,

$$\text{Mass (grams)} = k \frac{\text{Ionic weight}}{\text{valency}} Q.$$

Sources of Current and Electromotive Force. Having defined unit current and devised methods of calibrating meters to measure current in conformity with the definition of the unit, and having studied some of the effects of the current and determined their laws—particularly Faraday's laws of electrolysis—we turn to a study of sources of current such as voltaic cells, electrostatic, electromagnetic, and thermoelectric generators. We examine in a qualitative way the processes going on in these devices and classify the forces which act upon electrons in the sources of current and also the forces which act upon electrons in their movement through conductors and across surfaces. We classify these forces as the three elemental forces, namely, the electrostatic forces, the magnetic forces, and the inertial forces, and the composite forces such as the structural forces, the forces of chemical affinity between ions, the surface forces, the resistance force of impeding impacts and the surface impact force of thermionic emission. We conclude that since the non-electrostatic driv-

ing and impeding forces can be balanced against the electrostatic force, we may measure all the other forces through the electrostatic force. Now it was found to be far simpler in electrostatics to measure, not electric intensity directly, but the line integral of electric intensity; that is, potential difference. Accordingly in dealing with non-electrostatic forces we introduce and define a term which bears the same relation to these forces that potential increase bears to the electrostatic forces. The term is *electromotive force* and it is defined thus:

> When a specified type of non-electrostatic force acts upon electricity as it flows along a portion AB of a circuit, then the algebraic value (in that portion of the circuit) of the electromotive force in the direction AB of the specified type of force is defined to be equal to the work which is done by the specified forces per equivalent unit of positive electricity, which flows from A to B.

Thus the defining formula for electromotive force is

$$E \text{ (joules per coulomb) or (volts)} = \frac{W \text{ (joules)}}{Q \text{ (coulombs)}}.$$

When there is but a single kind of non-electrostatic force acting in the path AB the electromotive force from A to B is equal to the potential increase from A to B and may be measured by an electrostatic voltmeter connected from B to A.

When there are two or more kinds of non-electrostatic forces acting in a region the laws relating the values of these electromotive forces to the dimensions of the region and the processes going on therein are so formulated that they conform to the following general principle.

Electromotive Force Principle (Definition). In any given path, the algebraic sum of the electromotive forces in a specified direction along a path is equal to the potential increase from one terminal to the other in the specified direction.

This principle is generally known as Kirchhoff's electromotive force law. It is seen to be the method of applying the law of conservation of energy to electric circuits.

Voltage Current Characteristics of Conductors—Ohm's Law—Resistance. After defining electromotive force and making some study of the electromotive forces of batteries and thermocouples, we proceed to a study of the voltage-current characteristics of conductors.

(The speaker here described the experiment involved.)

For the case of the copper coils which do not rise in temperature appreciably and for the copper sulphate solution the student finds that a simple relation exists between the impressed electromotive force in the current, namely, the ratio of E to I is a constant. This is the relation discovered by Ohm and it should be stated thus:

> *Ohm's Law.* When an unvarying current flows through a given homogeneous metallic conductor which is kept at a constant temperature, the electromotive force between the terminals is directly proportional to the value of the current.

We then point out that this proportionality constant between voltage and current is of such importance that we assign a short name to it. We call it the resistance of the conductor and by decree we award to the unit of resistance the name *ohm*. Hence, the defining equation for resistance is

$$R \text{ (volts per amp.) or (ohms)} = \frac{E \text{ (volts)}}{I \text{ (amperes)}}.$$

In presenting Ohm's law we are rather insistent that the student shall recognize this as a conditional law determined by experiment to hold for a very limited range of conductors, and we are very insistent that in stating the law the student shall not draw the term "resistance" into the statement.

Magnetic Effects of the Current. The classic method of building up magnetic theory is to study the forces between magnetic needles, but if we follow this plan we make no use whatsoever of the electrical quantities which have been previously defined. To do so would be to make an independent

start and it would be necessary to define, in an arbitrary manner, the unit magnetic pole.

It is preferable to build up magnetic theory in terms of the quantities which we have already studied and defined. Since we find that a wire carrying a current experiences a force in the magnetic field set up by another coil, we devise what we call a *direction finding coil* for making a first study of the forces of the field. This direction finding coil is a coil having a diameter of 5 centimeters and containing 2,500 turns of No. 36 B. & S. copper wire. The coil is mounted on gimbals so that it is free to turn in any direction. A small test current is passed through the coil and it is used to explore the magnetic field set up by a large coil of wire. If the direction finder is held in any given position its normal axis points in a definite direction. If the coil is moved a few centimeters in the direction pointed out by the normal axis, the normal axis in the new position points in a slightly different direction. If the direction finder is moved in the new direction for several centimeters and the third direction noted and followed up, and if this is continued, it is found that a path is traced out such that the direction finding coil is returned to its starting point. Moreover, it is found that the path traced out by the coil always links with one or more turns of the coil which is setting up the magnetic field. We conclude that the direction finding coil traces out lines which we suspect will be very useful in describing the field.

We next devise a *force-finder* for the purpose of determining the laws relating to the magnitude of the force exerted on a conductor in a magnetic field. This force-finder consists of a straight wire, whose ends dip into mercury cups, which is suspended by silk threads from a framework which may be tilted through various angles. Through the mercury cups a test current is passed through the suspended wire. Upon setting the force-finder up in a field and determining the magnitude of the force acting on the wire by measuring the angle through which the frame must be tilted in order to keep the wire in the zero position, the following relations are found:

(*a*) The force is always perpendicular to the wire; that is, the wire never experiences a force which moves it in the direction of its length.

(*b*) The force is directly proportional to the length l of the wire and to the value of the test current I which the wire carries.

(*c*) If the wire is set up at a given point in a given field the magnitude of force depends upon the direction in which the wire points. If the wire points in the unique direction which is indicated by the direction assumed by the normal axis of the direction-finder, the wire experiences no force, and if the wire of the direction-finder makes an angle Θ with this unique direction the force on the wire is directly proportional to the sine of Θ.

In other words, the formula for the force on a short straight wire in a magnetic field is

$$f \text{ (dyne-sevens per cm.)} = BIl \sin \theta \text{ (amp. cm.)}$$

In this formula the proportionality constant B is a quantity which characterizes the magnetic field in the neighborhood of a point at which the force-finder is set up. It is a quantity whose value is independent of the proportions of a particular force-finder used in studying the field. If, then, we think of B as the quantity by means of which certain conditions at one point in the field may be compared with those at other points, it is evident that B must be regarded as having direction as well as magnitude, since both are necessary to completely specify the conditions at a point. B is therefore regarded as a vector quantity to which Maxwell gave the name *magnetic induction at a point* but which we now call the *magnetic flux density* at a point. We define the magnetic flux density in the following manner:

Magnetic flux density at a point P is defined to be a vector quantity whose direction is that singular direction through the point in which a short straight test wire carrying a current must be placed if the force on the wire

is to be zero, and whose magnitude is equal to the force upon the short straight test wire per centimeter of length and per ampere of test current when the direction of the test wire makes a right angle with the direction for zero force.

From this definition it is seen that the defining formula for magnetic flux density is

$$B \text{ (dyne-sevens per amp., cm.)} = \frac{f}{Il \sin \theta} \frac{\text{(dyne-sevens)}}{\text{(amp., cm.)}}.$$

The physically significant name of the unit of flux density is the dyne-seven per ampere-centimeter, and we expect the student to use this name until he is in a position to derive from secondary mathematical considerations the commonly used name; that is, the weber per square centimeter.

Force on a Charge Moving in a Magnetic Field. From the formula for the force on a conductor carrying current, a formula may be derived for the force on a moving charge. Thus, if the wire of the force finder is assumed to have an atmosphere of q_1 coulombs of free electricity per centimeter of length which is drifting through the wire with an average velocity of V centimeters per second, then the current in the wire has the value

$$\text{I (amperes)} = q_1 V \text{ (coulombs, cm. per sec.)}$$

Upon substituting this value for the current in the force formula and noting that the product of q_1 and l is the total moving charge Q, it is seen that the formula for the force on a charge Q moving with a velocity V takes the form

$$f \text{ (dyne-sevens)} = QVB \sin (V, B)$$

Prediction of Magnetic Flux Densities. Having defined magnetic flux density in terms of the force on a wire and having devised force finders for measuring the magnetic flux density, the next problem is to learn how to predict from the dimensions of the coils giving rise to the field, the value of the magnetic flux density at any point in the field. This knowledge is needed to permit of the design of motors, etc.

By analyzing experimental data obtained from simple experiments, Ampere, within four weeks after the announcement of Oersted's discovery of the magnetic effect of the current, was able to deduce the formula for computing the flux density at any point in the magnetic field of coils of known configuration (free of ferro-magnetic materials) carrying known currents.

$$B = \Sigma\mu \frac{I \sin (r, l)dl}{4\pi r^2}.$$

Alternative Methods of Expressing Ampere's Formula. A study of the line integrals and surface integrals of the magnetic flux density is then taken up, and the magnetomotive force law of circuitation and the law of continuity are derived and these are presented as alternative ways of expressing the relations contained in Ampere's formula. The magnetomotive force law is first expressed in the following form:

> The line integral of the magnetic flux density around any closed loop is proportional to the surface integral of the current over any cap bounded by the loop

$$\int_{\text{closed line}} B \cos (B, l)dl = \mu\Sigma I = \mu \int_{\text{cap}} J \cos (J, n)da.$$

The law of continuity is expressed in the form—the surface integral of the magnetic flux density over any closed surface is zero.

$$\int_{\text{closed surface}} B \cos (B, n)da = 0.$$

At this point the term "magnetic flux" is introduced, together with the arbitrarily coined name for the unit of flux, namely, the *weber;* and the student is then in a position to derive and to use the commonly accepted name of the unit of flux density, namely, the *weber per square centimeter.*

Motional Electromotive Forces. After this study of the laws for the force on a conductor carrying a current and this derivation of formulas for predicting the value of the flux density, we next take up the derivation of the laws and formulas relating to the forces tending to set electricity in a wire in motion when the wire moves in a magnetic field. It was Faraday's achievement, after six years of search, to discover the methods by which currents could be set up or generated in a magnetic field. Faraday knew that charged bodies induced charges in other bodies, that magnets induced a magnetic state in soft iron, and he reasoned by analogy that a current in one circuit might induce a current in an adjacent circuit. After the six years of search he discovered and proceeded to elucidate with remarkable clearness the conditions under which currents are induced in adjacent circuits by reason of the current in an independent circuit. He found that currents were set up or, rather, that electromotive forces were induced if he moved the circuits relatively to each other or if he varied the value of a current in one circuit.

In our development of the subject we follow the plan used by Faraday in deriving the quantitative laws relating to motional electromotive forces. We devise a voltage-impulse meter (a ballistic galvanometer) and calibrate it empirically by means of a voltage impulse switch.

The next experiment deals with the calibration of the voltage-impulse meter by empirical methods. In this experiment the student is provided with a rotating switch. By means of this switch he impresses different voltages for different short intervals of time across the terminals of the ballistic galvanometer and observes the throw of the galvanometer corresponding to each voltage-impulse. He plots the relation between throw and voltage-impulse (finding it to be a straight line relation) and thus has calibrated his meter to read the values of voltage-impulses.

In the next experiment the student uses the calibrated ballistic galvanometer to measure the voltage-impulses which are induced in the coil which he moves and flips in various ways in the magnetic field. The conclusion of all of these experi-

ments is that the voltage impulse induced in a coil of N turns is precisely equal to the product of the number of turns times the increment in the magnetic flux linked with the coil. Writing this relation in the form of an equation

$$\int e dt = -N(\text{increment of flux}).$$

The unique feature of this relation is that the voltage-impulse of a motionally induced electromotive force (which at this stage in this study is a new phenomenon, as yet unaccounted for in terms of other electrical phenomena) should turn out to be *exactly equal* to the product of the factors appearing in the right member of the equation. Things rarely happen this way in nature. Proportionality constants always turn out to have some odd decimal value, such as 3.1416 or 2.54 or 32.16, and never turn out to be unity except under one of two conditions:

1. When the new quantity has been defined in terms of the more familiar antecendent quantities in such a manner as deliberately to make the proportionality constant in the defining equation unity.

2. When the new phenomenon turns out to be but another aspect of a phenomenon whose measure appears on the right side of the equation.

Now we have not consciously defined the "voltage-impulse of a motionally induced electromotive force" in terms of any of the factors appearing in the right member of the equation, and this empirically determined equality should have an important physical significance. We then proceed to show that a motional electromotive force, or a line integral of a force on the electrons in a moving conductor, is but another aspect of the force in terms of which magnetic flux density has been defined.

(The speaker continued by describing the following experiments; mapping of flux densities by means of a flip-coil, electromotive forces of inductance, electromagnetic inductance between lines, magnetic fields containing ferro-magnetic material.)

Conclusion. This outline of the method of teaching electrodynamics has necessarily been very sketchy. In the presentation of the relations between the units to students I have advocated:

1st—That the relations between the units (electric and magnetic) be developed in a *consecutive* sequence, and that the starting point for the development be the electrostatically defined unit charge—the coulomb.

2d—That beginning students be taught to carry on their calculations in a single system of units and not in a mixture of three systems, and that the system taught be the pure practical system, or ampere-ohm-volt-watt-weber system—a system from which the multitude of arbitrary conversion factors has been eliminated.

3d—That the system of units taught to students be freed of the irrational 4π factors by the simple expedients of using the ampere-turn instead of the gilbert as the unit of magneto-motive force, and the permittivity instead of the dielectric constant of the medium.

4th—That students be burdened with the relations between the electrostatic, electromagnetic, the Heaviside and the hybrid practical systems only after they have learned to think in terms of a simple factor-free system.

It is hoped that the presentation has sufficiently illustrated a method of embodying these features in a course in electrodynamics and has called attention to the better correlations which result from a consecutive inductive development of the relations.

THE TEACHING OF THE ELEMENTS OF ELECTRICAL ENGINEERING: CIRCUITS

By William R. Work

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July 12, 1928

The scope of this paper on the teaching of "Circuits" will be limited to the treatment of certain fundamental phenomena and principles associated with:

(*a*) The conducting circuit,
(*b*) the magnetic circuit,
(*c*) the dielectric circuit.

In the institution with which the speaker is connected the introductory course in elements of electrical engineering begins in the first semester of the Sophomore year. The students carry calculus concurrently, having already had some of the elements of this subject in the Freshman year. They are also just beginning their college physics. This fact is mentioned because it has a bearing on the method of presentation of the topics in elements of electrical engineering. The Department of Physics, a department of the College of Engineering, actively cooperates with the Department of Electrical Engineering in coordinating the work in electricity and magnetism with the course in elements of electrical engineering.

The scheduled classroom hours for the course in elements of electrical engineering call for one lecture period and one recitation period per week throughout the year. The laboratory exercises are intimately related to the work in the classroom.

The students prepare for the lecture by studying the subject matter contained in definitely assigned paragraphs in the textbook. During the lecture hour the teacher supplements the treatment in the textbook with such material as his experience indicates will be most effective in giving the students a thorough understanding of the principles. Many practical examples are used because it is believed that this

method develops the student's ability to recognize in an actual case the fundamental principles or principles involved.

Sometimes the whole lecture period is taken up by demonstration with apparatus. Sometimes the reproduction of a diagram from the text, built up, element by element, in colored crayons on the black-board as the discussion proceeds, accomplishes this purpose. Frequently a question asked by a student serves excellently as a basis for a general and fruitful debate.

For the recitation hours the class is divided into sections of not more than twenty members each. Five problems taken from the text and assigned one week in advance constitute an average task for one recitation hour. The problems themselves are selected to cover a considerable range with respect to degree of difficulty. A number of them, scattered throughout the course, are hard enough to cause the best men in the class to extend themselves to effect solutions. It has been found quite practical to assign some of these harder problems to be submitted in written form with no definite due date other than the end of the semester. The student prepares for the classroom work by solving the problems. He may check his answers against an answer book if such is available. He may cooperate with other students in working the problems. It makes no difference to the teacher *how* he learns to make the solution; learning *how to do it* is the important thing.

In the classroom the entire section is sent to the black-board. Each student is assigned a problem which he must attack without direct aid from any previously prepared solution on paper. The instructor circulates round the room, noting mistakes and trying by questions to make the student find his own way out of his difficulty. As soon as a man achieves a correct solution, he is assigned another problem. Usually forty minutes are devoted to this board work, the remainder of the period being used by the instructor in discussing characteristic faults and errors.

It is important to incorporate in the problems, as the course progresses, principles studied earlier. The student must not be allowed to feel that separate chapters in the textbook repre-

sent blocks of knowledge which he can stow away in his mind for ready use at some indefinite future time.

The initial exercise in a course in "Circuits" may logically enough be devoted to the electrical quantities and phenomena associated with a simple series circuit. What foundation does the student have upon which to begin to build? The modern student may safely be assumed to have had certain experiences with electricity in his home, about the family car, and in his radio set, which have given him a small fund of information which the instructor can and should use to advantage. Also he learned, as far back as his high school days, that "I equals E over R," and can recite this glibly. The special problem for the teacher, at the outset of the course, is to draw out, work over, and supplement the student's immature knowledge until the true inwardness of the meaning of electro-motive force, quantity, current, and resistance is made clear.

The student is quite able and willing to accept the view that electricity is "granular," that conductors contain free electrons which normally move about among the atoms in an inorganized way, but which may be organized into a "parade" or current by the introduction of an electromotive force in a closed conducting path.

At first no attempt need be made to justify or explain in detail the size of the coulomb or the size of the volt. Also, at first the ampere is simply defined as a coulomb per second.

After the discussion of the simple circuit, the next major topic is Kirchhoff's laws. Students regularly, at first, have trouble here out of all proportion to the real difficulty of the subject. They lack confidence in applying the laws to actual cases. It takes some hard work on the part of the instructor to instill that confidence and to bring the class to the point where they can face a network, sprinkled over with sources of electromotive force, without a shudder. Extensive problem drill seems to be the only solution.

Having developed the concepts of resistivity and conductivity and having used these in the computation of the resistances of conductors of uniform section, it is desirable to take

up problems involving conductors of non-uniform section. Here is a chance to discuss current density as related to voltage gradient and to make some preparation for the treatment of analogous relations in the magnetic and dielectric fields.

After dealing with circuits involving only conductors of constant resistance, that is, a strictly linear relation between voltage and current, variable-resistance circuits may profitably be taken up. Here a radically different mode of attack must be used. The concept of resistance as a simple ratio between voltage drop and current must be abandoned as of little or no use. Instead, use is made of experimental data in the form of graphs showing voltage drop as a function of the current strength. Lamps of different sizes in series or in parallel or in semi-parallel, ballast resistors, arc circuits, all may be used as examples. Problems of this kind serve a double purpose; they not only extend the student's ability to solve circuits but they also introduce him to a mode of solution which he will use in magnetic circuits and other work later.

The study of the magnetic circuit may conveniently be introduced by the consideration of the magnetic field about a straight wire carrying current. The motion of magnetic flux surrounding the current and its direction as related to the direction of the current is first discussed. Considering the wire to be bent in a circular form, the magnetic flux associated with a simple loop is taken up. Next the magnetic flux within and without an air-core solenoid is studied quantitatively, considering the solenoid to consist of single loops, side by side. Finally the solenoid, bent until its ends meet, produces a form of magnetic circuit suitable for the initial quantitative calculations.

The next step is to show the linear relation between flux and exciting current and that "this leads to an Ohm's law" for the magnetic circuit. The concepts of m.m.f., magnetizing force, flux, flux density, reluctance, reluctivity, and permeability are then developed and compared with the analagous quantities in the electric circuit. As to units, it is better to avoid, at first, the use of inches, adhering to the c.g.s. values.

Proceeding to iron-cored circuits, the attention of the stu-

dent is directed to a symmetrical iron ring uniformly wound with a magnetizing winding, an arrangement exactly similar to the preceding endless solenoid in every respect except that the core is of iron and not of wood or air. It is demonstrated that the new magnetic circuit differs from the old in two important particulars: first, for the same value of magnetizing current the flux is much greater; second, that the flux is no longer directly proportioned to the current.

Typical B-H curves, for various irons and steels, are then displayed and a basis laid for the use of such curves in solving magnetic circuit problems.

With this preparation, certain problems relating to magnetic fields about linear conductors and coils may be taken up. Laplace's law applied to a straight filament carrying current yields an expression for the flux density at any point in space as a function of the current strength and the coordinates of the point. For a point near a very long wire, the expression takes a simple form. Here is a chance to discuss the question of the relation between a rational formula of complex form and a simpler formula which will yield all requisite accuracy in computation.

The formula just derived is applied to find the expression for the flux density both outside and inside a thin-walled tube of circular section, considering the tube to be made up of parallel filaments carrying currents along their length.

By regarding a solid wire as composed of a number of concentric thin tubes, expressions for the flux density both outside and inside a solid wire follow from the foregoing.

The derivation of the expression for the flux density within a solenoid is handled in the same general way. First, the formula for the flux density on the axis of a circular current is found by the aid of Laplace's law. This result is then applied to the case of the solenoid by considering it to be composed of a number of similar circular current elements, side by side.

Such problems not only produce results valuable in themselves, but they also serve as excellent examples of rigorous mathematical analysis and of essentially rational relationships between physical quantities.

To introduce the study of dielectric phenomena, consideration may first be given to the electric field between a pair of parallel metal plates, insulated from each other and held a fixed distance apart. Beginning with the linear relationship between the quantity of electricity displaced and the potential difference between the plates as an experimentally demonstrated fact, the idea of capacitance as the ratio between quantity and potential difference is developed. The concept of dielectric flux as representing quantity of electricity and the direction and distribution of dielectric flux follow. At this point extensive use of the magnetic circuit and of the conducting circuit as analogies may be made with considerable advantage.

Confusion in units may be avoided by accepting permittivity as an experimentally determined constant (for any medium), comparing it with conductivity.

Alternating current circuits are taught in a course which comes in the second semester of the Junior year, three class hours and three laboratory hours per week. This course is operated in rather an orthodox fashion, a standard text being used and followed closely. The same general mode of presentation is used here as in the introductory course, save that the ratio between lecture hours and problem hours is reduced.

At the outset a special effort is made to get the student to see that he is going to solve alternating current circuits in precisely the same manner as he solved direct current circuits, only the mathematical operations involved call for some additions to his kit of mathematical tools.

In order to emphasize the geometrical character of the solutions, the initial problems involving numerical values of currents and voltages in series circuits are required to be solved graphically.

Appreciation of the meaning of a complex number appears to be one of those things which a student finds difficult to get in a mathematics course. Furthermore some time has elapsed since he had that subject. It therefore seems necessary to allow time in a course on alternating currents for a review of complex numbers.

Proceeding to the solution of simple circuits by the complex quantity method, the same problems given for graphical solution may be reassigned, so that the original answers may be used as a check on the answers obtained by the more exact analytical method.

In the solution of net works, whether single-phase or polyphase, the use of double subscripts to indicate the positive sense of a current or voltage has been found to be preferable to the use of arrows to show the same thing.

THE FUNCTION OF THE LABORATORY IN ELECTRICAL ENGINEERING COURSES

By H. E. Dyche

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July 16, 1928

The answer to the title of this paper may be given in one sentence. The function of the laboratory is to further develop the work of the classroom in such a way as to produce the best possible results in the training of the electrical engineer. Just how the work of the laboratory should be organized to produce such results will require consideration of quite a number of factors, all of which have a definite bearing upon this question.

Laboratory Work in Foreign Institutions. My experience in this connection is limited to interviews with men who have had a portion or all of their training in foreign institutions. In almost every case I have been impressed by the fact that there is little or no laboratory requirements in electrical engineering in the curricula of foreign institutions. I believe that this lack of laboratory training shows up quite markedly in the work of such men who enter upon an electrical engineering career in this country. It seems to me that engineering education in this country and electrical engineer-

ing in particular, has grown up around the laboratory idea. Much of the early engineering training was devoted almost exclusively to laboratory study, while the developments and progress in the manufacturing field, were almost invariably the result of the cut and try process.

There is but little question, therefore, that the laboratory idea has become the backbone of most of our training in electrical engineering. In fact, I have a feeling that we have become so accustomed to the laboratory idea that we are inclined in some cases, to allow it to carry on, along the lines of least resistance.

Recitational Instructors Should Give Some Laboratory Work. It has become almost universal practice in this country to delegate laboratory instruction to the younger members of the staff—men who are, in many cases, of the rank of student assistant. Very often such men are graduates of the institution in which they are giving instruction. To my mind, principles of good teaching can not justify a situation of this kind. We all recognize the fact that the purpose of any laboratory course is to correlate in a proper manner the material of the classroom. I do not care how carefully your corps of laboratory assistants is coached, it is impossible for them to bring about the degree of correlation which is so necessary for the proper development of the laboratory instruction. As a result of a situation of this kind the student is the first to feel this lack of coordination. You immediately reply to this statement: "It is impossible for recitational instructors in a large department to give the laboratory instruction associated with their particular course." Quite true, but it is still possible for this instructor to carry at least one section of laboratory work. In this way he will be able to bridge the gap which otherwise would exist between the classroom and the laboratory. His experience with this one section in the actual development of the laboratory course will enable him intelligently to direct the other assistants who may be giving the remainder of the work.

Length of the Laboratory Period. This question always

comes up for consideration in a subject of this kind. In most common use is the three-hour laboratory period, for which one-half, one, or perhaps two credits are allowed. Recently, however, I believe there is a tendency to swing into the two-hour laboratory period with a one-hour credit. The length of these periods depends somewhat on the content of the curriculum, particularly with reference to the amount of other laboratory work required. Here at the University of Pittsburgh, we use the three-hour laboratory period. In a one semester course in elementary electricity given in the Sophomore year, we have a three-hour laboratory period scheduled—the first hour of which is devoted to a laboratory lecture by the laboratory instructor. I am a great believer in this general method of introducing the laboratory work. I believe that a great deal can be accomplished toward the effectiveness of the laboratory period with as little as a ten-minute introductory lecture on the particular experiment in hand. Sometimes it may be desirable for the instructor to give a demonstration lecture as a part of the laboratory period. In the Junior and Senior years we are not so insistent upon the laboratory lecture idea as in the beginning course. This, however, is left largely to the discretion of the instructor.

Size of Test Squad and Laboratory Group. The laboratory group and the size of the test squad is a subject very closely related to the previous one. This is, of course, like other phases of this subject, variable. In the elementary courses dealing largely with circuit measurements, etc., a larger group may be directed by a single instructor—perhaps as many as sixteen or, at the most, twenty. On the other hand, machine experiments should be limited to three or not to exceed four squads; having three students to a squad, making a minimum of nine per section, or four per squad—making a maximum of sixteen to a section.

Laboratory Instruction Sheets. You will note that I open this discussion under the head of "Laboratory Instruction Sheets" and not Laboratory Direction Books. While there is quite a number of very desirable laboratory direction

books on the market, I have a feeling that they are very little used. I believe that for the most part, each institution prefers to develop its own laboratory outlines and direction sheets. If your experience has been similar to mine, you will have found that it is impossible to develop a set of laboratory instructions in your department which will stand without considerable revision for as much as two years.

Reducing the Time Required for Laboratory Reports. Shortly after the reports of the Board of Investigation and Coordination became available, we at the University of Pittsburgh along with many other institutions, realized that we were requiring too much time expenditure on the part of our students. In our paring down process, we agreed that some radical changes should be made in our method of laboratory report preparation. Up until that time the conventional report was required on the part of every student after the completion of a laboratory assignment. As I look back on this situation I feel that our requirements were unjustified. The preparation of the laboratory report usually required an expenditure of from four to six hours. This, added to the three-hour period made a total time expenditure on the part of the student from six to nine hours, for which we granted him the magnificant credit of one hour. On the other hand, a recitation period of one hour and perhaps one hour preparation would be worth one credit. I can not help but emphasize this fact and I feel that we have been most unfair with our students not only in this institution, but in other institutions as well, in this question of laboratory credits.

Then too, we must consider this question in connection with training the student in the writing of engineering reports. As a matter of fact we are often told by students after graduation that much of their valuable experience in the writing of engineering reports was obtained in the writing of laboratory reports while in school. I still have a feeling, however, that a more satisfactory method of instruction in engineering report writing may be obtained in other ways, although the laboratory report is still a contributing factor. To eliminate

some of this difficulty, we are trying some different methods at the present time. The student is required to submit a report for his first laboratory assignment of the semester. He is advised beforehand that if this report is of a satisfactory nature, he will be excused from all further formal report writing for that semester. Herein enters the competitive idea. Some students will qualify on this basis after two or three reports. Others will require more. You ask—what method of laboratory reporting is used for the remaining experiments? This brings me to the consideration of the next item.

The Test Book Idea. Those of you who have been in the employ of the Westinghouse Electric and Manufacturing Company will recognize immediately the test or calculation book to which I refer. As a matter of fact, the book in use at the University of Pittsburgh is a duplicate, as nearly as possible, of the one in use by the Westinghouse Company. It has cross-section ruling on one page, the opposite page being blank. With suitable titles at the top of each page, it lends itself quite readily to the needs of the engineering laboratory. I might add, also, that we find the students adopting these books for other laboratories and other purposes. The use of this book in the laboratory becomes evident at once. Sufficient time near the close of the three-hour laboratory period is allowed for the student to make the necessary calculations and plot in pencil such curves as may result. It is possible, of course, in some cases to plot curves as the test results are being obtained. In this way, the student immediately recognizes any data that may be in error. Laboratory instruction sheets are given the student in such a way that the sheets may be placed in the test book at the proper place.

The Complete Unit Test and One Report. This portion of our subject would not be complete without some reference to the complete unit test and one report. While by no means a new idea, it lends itself quite readily to a reduction in the amount of routine report writing. We use this plan, in some

cases reducing the report writing to as little as one comprehensive report each semester.

For example, in our course in beginning alternating currents in the Junior year, five laboratory periods, or five weeks, are devoted to circuit studies at the conclusion of which one report covering this work is submitted. In the Senior year, in the continuation of this course, we require, for example, one report on the general subject of the transformer and another on the subject of the induction motor. These reports are written in the form of a letter covering the story of the laboratory findings.

The Semi-standardized Courses. After a good many years of laboratory survey in one way or another, I have come to the conclusion that our laboratory courses are more nearly standardized than we realize. It is not the purpose of this paper to consider the types of laboratory courses desirable in a curriculum, but only the possible methods of teaching and operation. I believe, however, that about ninety percent of our electrical engineering laboratory instruction comes under the following heads:

1. The elementary or Sophomore course,
2. The d. c. power laboratory,
3. The a. c. power laboratory,
4. The photometric laboratory,
5. The communication laboratory, including radio,
6. The electrical measurements laboratory.

I shall not take the time to discuss these different courses, except to refer to the last one on electrical measurments. Shall this course be given under the direction of the physics department or will it be a definite part of the instructional work in the electrical engineering department? I imagine the consensus of opinion on this matter is pretty evenly divided. To indicate my own views, however, I very strongly favor this type of instruction being given under the direction of the physics department. If a cordial cooperative relationship exists between the staffs of the two departments,

a very excellent course of instruction may be worked out. Every physics department, whether instruction is given for electrical engineers or not, must necessarily have some equipment for electrical measurements work. If the electrical engineering department gives such instruction, there is necessarily a duplication of equipment.

Because of the semi-standardization of many of our courses, I believe it would be comparatively easy to work out a more or less uniform method of procedure in such courses. It would be interesting to see what our Committee on Laboratory Work could do in this connection. I appreciate, of course, the importance of variations in these different courses to meet special requirements in certain institutions.

Laboratory Examinations. Much has been said during this session concerning the unit idea in teaching and particularly the desirability of check tests on such units. Have you ever tried laboratory examinations? I do not mean the customary question and answer type of laboratory experiments. Suppose you go through your dynamo laboratory and put the motors and generators out of commission by introducing some defect into the machines—an open field circuit, raised brushes, reversed polarity, and in general introducing "bugs" in the equipment wherever possible. In short, a trouble shooting examination.

Again, have a number of simple questions requiring laboratory set-up or performance, written on index cards, each one having a time limit of say ten, fifteen, or thirty minutes. Then rate each student or squad on their ability to meet the requirements. I am sure you will get some interesting results from such examinations.

Permanent versus Flexible Laboratory Set-up. Personally I am very much against the idea of a fixed laboratory set-up, and it seems to be rather widely used in many institutions. The student should be required to wire up even the driving motor, when he is making a generator test. Making ready for the test requires initiative, and is of great value to the

student. To simply connect a meter, throw a switch, and take a reading is not laboratory work.

Standard Laboratory Equipment. Perhaps a consideration of this subject is somewhat out of line with this general topic, but I feel it is desirable to make some mention of it. I know that this subject is of considerable interest to the manufacturing companies. Glance through their publication "Equipment for Technical Schools" and you will find every indication that they are attempting to provide such equipment, without a very clear idea of what it is all about. Considering the question of dynamo machinery, I feel it is a mistake to have the manufacturers develop special types of machines. I think we should use commercial types wherever possible. Other items which might be considered are: standardized terminals, panels, jacks and plugs, loading coils, inductive and capacity units.

Coordination of Laboratory and Recitation Most Essential. The recitational instructor who gives his own laboratory instruction realizes very keenly the problem of speeding up the work of the poor student and making things interesting for the stronger student. In order to complete the work on schedule, shall we coach the weaker student in order that he may complete the assignment in the time allotted, or shall he complete as much as possible and leave the remainder? Quite often the laboratory instructor in order to unify his work, actually performs some of the work for the weaker student. In other words, the conscientious laboratory instructor has the same fundamental teaching problems to contend with as does the instructor in the class room.

In conclusion, let me repeat what I said in the beginning, namely, that the most successful laboratory course is that given by the instructor who also teaches the recitational work in that particular course. We may all differ in many of the details by which we work out the technique of our laboratory procedure, but after all is said and done, the thing of greatest importance is that of coordination.

MICHAEL FARADAY

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Michael Faraday was born at Newington in Surrey on September 22, 1791, and he fell asleep in his chair in his study on August 25, 1867. Faraday's immediate forefathers lived in a little place called Clapham Wood Hall in Yorkshire. Here dwelt Robert Faraday and Elizabeth, his wife, who had ten children, one of them James, born in 1761, being father of Michael. A family tradition exists that the Faradays originally came from Ireland. Michael Faraday could imitate the Irish brogue and his wonderful vivacity may have been in part due to his extraction. He had a very high sense of order which ran like a luminous beam through all the transactions of his life. In his "Experimental Researches," he numbered every paragraph and welded their various parts together by incessant reference. His private notes were similarly numbered; their last paragraph bears the figure 16,041. His working qualities showed the tenacity of the Teuton. His nature was impulsive, but there was a force behind the impulse which did not permit it to retreat. If in his warm moments he formed a resolution, in his cool ones he made that resolution good. Thus his fire was that of a solid combustible, not that of a gas, which blazes suddenly, and dies as suddenly away.

Letters to his friends always contained some characteristic utterance; strong, yet delicate in counsel, joyful in encouragement, and warm in affection. He prized the love and sympathy of men; prized them almost more than the renown which his science brought him. He once remarked to his friend, John Tyndall: "Tyndall, the sweetest reward of my work is the sympathy and good will which it has caused to flow upon me from all quarters of the world." This love

of his friends is shown in the following quotation from a letter to a friend:

> "The monk, for the chastisement of his body and mortification of his sensual lusts and worldly appetites, abstains from pleasures and even the simple supplies that nature calls for; the miser, for reasons as strong though diametrically opposite —the gratification of a darling passion—does exactly the same, and leaves unenjoyed every comfort of life; but I, for no reason at all, have neglected that which constitutes one of my greatest pleasures, and one that may be enjoyed with the greatest propriety, till on a sudden, as the dense light of the electric flash pervades the horizon, so struck the thought of my friend Abbot through my soul."

There was no trace of asceticism in Faraday's nature. He preferred the meat and wine of life to its locusts and wild honey. He never discussed religion except when drawn into it. He then spoke without hesitation or reluctance; not with any desire to improve the occasion but to give such information as was sought. He believed the human heart to be swayed by a power to which science or logic opened no approach and, right or wrong, this faith held in perfect tolerance of the faith of others, strengthened and beautified his life.

In 1804, when Faraday was 13 years of age, he was apprenticed to a bookseller and bookbinder where he spent eight years, after which he worked as a journeyman elsewhere. Faraday's indentures as an apprentice are dated October 7, 1805: one line of which is worthy to be kept—"In consideration of his faithful service, no premium is given."

He took notes of Sir Humphrey Davy's lectures before the Royal Institution, wrote them out, and sent them to Davy entreating him at the same time to enable him to quit trade, which he detested, and to pursue science, which he loved. Davy advised him to keep in business as a bookbinder and promised him his work, and that of the Institution and of many friends. Later he recommended Faraday to the managers of the Royal Institution. This was in 1813. Davy was Professor of Chemistry and Director of the Laboratory and

was very helpful to Faraday, making him his assistant. Davy was a great friend of Mr. Pepys and upon asking him what to do concerning employment for Faraday, Mr. Pepys advised "Do? put him to wash bottles; if he is good for anything he will do it directly, if he refuses he is good for nothing." Faraday was engaged at a weekly wage of 25 s. to assist in the laboratory. When Davy gave up his connection, he insisted that Faraday should be appointed Director of the Laboratory, which was done.

Faraday claims that he found the beginning of his philosophy while an apprentice in the bookshop. He gained his first notions of electricity from the *Encyclopædia Brittanica*, and *Conversations on Chemistry* gave him his foundation in that science. He says: "Facts were important to me, and saved me. I could trust a fact, and always cross-examined an assertion."

Faraday was married on June 12, 1821. He was 30 and she was 21. In his 46 years with Mrs. Faraday he added *chivalry* to his affection for her.

Oersted, in 1820, discovered the action of voltaic current on a magnetic needle; immediately afterwards Ampere succeeded in showing that every magnetic phenomenon then known might be reduced to the mutual action of electric currents. The subject occupied all men's thoughts and in England Wollaston sought to convert the deflection of the needle by the current into a permanent *rotation* of the needle around the current. He also hoped to produce the reciprocal effect of causing a current to rotate round a magnet. Early in 1821 Wollaston attempted to realize this idea in the presence of Sir Humphrey Davy in the laboratory of the Royal Institution. This attracted Faraday's attention. On Christmas morning 1821 he called his wife to witness for the first time the revolution of a magnetic needle round an electric current.

The same year he also touched upon the vaporization of mercury at common temperatures; and immediately afterwards conducted, in company with Mr. Stodard, experiments on the alloys of steel. He was accustomed in after years to

present to his friends razors formed from one of the alloys then discovered.

During Faraday's hours of liberty from other duties he took up subjects of inquiry for himself and in the spring of 1823 he began the examination of a substance which had long been known as the chemical element chlorine, in a solid form, but which Sir Humphrey Davy, in 1810, had proved to be a hydrate of chlorine. Faraday first analyzed this hydrate and wrote out an account of its composition. This account was looked over by Davy who suggested heating the hydrate under pressure in a sealed glass tube. This was done. The hydrate fused at a blood-heat, the tube became filled with a yellow atmosphere, and was found to contain two liquid substances. Dr. Paris entered the laboratory while Faraday was at work. Seeing the oily liquid in the tube he rallied the young chemist for his carelessness in employing soiled vessels. On filing off the end of the tube, its contents exploded and the oily matter vanished. Early next morning, Dr. Paris received the following note:

> "Dear Sir: The *oil* you noticed yesterday turns out to be liquid chlorine.
>
> Yours faithfully,
> M. Faraday."

Faraday continued his experiments and succeeded in reducing a number of gases till then deemed permanent to the liquid condition. These important investigations established the fact that gases are but the vapors of liquids possessing a very low boiling point, and gave a sure basis to our views of molecular aggregation.

In 1825, Faraday, in a paper published in *Philosophical Transactions* on new componds of carbon and hydrogen, announced the discovery of benzol which has become the foundation of our aniline dyes.

Faraday swerved incessantly from chemistry to physics. In 1825 he became a member of the committee, appointed by the Royal Society, to examine, and if possible, improve the manufacture of glass for optical purposes. Their experi-

ments continued until 1829, when an account of them constituted the subject of a "Bakerian Lecture." This lectureship founded in 1774 by Henry Baker, Esq., of the Strand, London, provides that every year a lecture shall be given before the Royal Society, the sum of four pounds being paid to the lecturer. The Bakerian Lecture has long since passed from the region of pay to that of honor, papers of mark only being chosen for it by the Council of the Society. Faraday's first Bakerian lecture "On the Manufacture of Glass for Optical Purposes" was a very elaborate and conscientious description of processes, precautions and results. The details were so exact and so minute and the paper so long that three successive sittings of the Royal Society were taken up by its delivery. This glass did not turn out to be of important practical use.

In 1831, Faraday published a paper "On the Peculiar Glass of Optical Deceptions" to which the beautiful optical toy called the Chromatrope owes its origin.

The work referred to above, though sufficient of itself to secure no mean scientific reputation, forms but the vestibule of Faraday's achievements. He had been engaged in the Royal Institution for 18 years. During that time he had absorbed knowledge from Sir Humphrey Davy, and also exercised his capacity for independent inquiry. In 1831 we have him at the climax of his intellectual strength, 40 years of age, stored with knowledge and full of original power. Through reading, lecturing and experimenting, he had become thoroughly familiar with electrical science. He saw when light was needed and expansion possible. The phenomena of ordinary electric induction belonged, as it were, to the alphabet of his knowledge. He knew that under ordinary circumstances the presence of an electrified body was sufficient to excite, by induction, an unelectrified body. He knew that the wire which carried an electric current was an electrified body, and still that all attempts had failed to make it excite in other wires a state similar to its own.

Faraday never could work from the experiments of others, however clearly described. He hardly trusted himself to

reason upon an experiment he had never seen. It is worth while for us to dwell for a moment on the power which Faraday possessed in an extraordinary degree. He united vast strength with perfect flexibility. His momentum was that of a river, which combines weight and directness with the ability to yield to the flexures of its bed. The intentness of his vision in any direction apparently did not diminish his power of perception in other directions; and when he attacked a subject, expecting results, he had the faculty of keeping his mind alert, so that results different from those which he expected should not escape him through pre-occupation.

He began his experiments on the induction of electric currents by composing a helix of two insulated wires which were wound side by side round the same wooden cylinder. One of these wires he connected with a voltaic battery of ten cells, and the other with a sensitive galvanometer. When connection was made with the battery, and while the current flowed, no effect whatever was observed on the galvanometer. But he never accepted an experimental result until he had applied to it the utmost at his command. He raised his battery from 10 cells to 120 cells, but without avail. The current flowed calmly through the battery wire without producing, during its flow, any sensible results upon the galvanometer.

"During its flow," and this was the time when the effect was expected—but here Faraday's power of lateral vision, separating, as it were, from the line of expectation, came into play—he noticed that a feeble movement of the needle always occurred at the moment when he made contact with the battery; that the needle would afterwards return to its former position and remain there quietly unaffected by the *flowing* current. At the moment, however, when the circuit was interrupted the needle again moved, and in a direction opposed to that observed on the completion of the circuit.

This result, and others of a similar kind, led him to the conclusion "that the battery current through the one wire did in reality induce a similar current through the other; but that it continued for an instant only, and partook more of the nature of the electric wave from a common Leyden jar than

of the current from a voltaic battery." The momentary currents thus generated he called *induced currents,* while the current which generated them was called the *inducing* current. It was immediately proved that the current generated at making the circuit was always opposed in direction to its generator, while that developed on the rupture of the circuit coincided in direction with the inducing current. It appeared as if the current on its first rush through the primary wire sought a purchase in the secondary one, and, by a kind of kick, impelled backward through the latter an electric wave, which subsided as soon as the primary current was fully established.

Faraday for a time believed that the secondary wire, though quiescent, when the primary current had once been established, was not in its natural condition, its return to that condition being declared by the current observed at breaking the circuit. He called this hypothetical state of the wire the *electrotonic state;* he afterwards abandoned this hypothesis, but seemed to return to it in later life.

The mere approach of a wire forming a closed curve to a second wire through which a voltaic current flowed was then shown by Faraday to be sufficient to arouse in the neutral wire an induced current, opposed in direction to the inducing current; the withdrawal of the wire also generated a current having the same direction as the inducing current; those currents existed only during the time of approach or withdrawal, and when neither the primary nor the secondary wire was in motion no matter how close their proximity might be, no induced current was generated.

Faraday has been called a purely inductive philosopher. But the real vocation of an investigator like Faraday consists in the incessant joining of both. Faraday began the attempt to effect the evolution of electricity from magnetism. Round a welded iron ring he placed two distinct coils of covered wire causing the coils to occupy opposite halves of the ring. Connecting the ends of one of the coils with a galvanometer, he found that the moment the ring was magnetized, by sending a current through *the other coil,* the galvanometer needle

whirled around four or five times in succession. The action, as before, was that of a pulse which vanished immediately. On interrupting the circuit a whirl of the needle in the opposite direction occurred. It was only during the time of magnetization or demagnetization that these effects were produced. The induced currents declared a *change* of condition only, and they vanished the moment the act of magnetization or demagnetization was complete.

The same effects were obtained with straight bars of iron. The use of iron was then abandoned and the same effect was obtained by merely thrusting a permanent steel magnet into a coil of wire. A rush of electricity through the coil accompanied the insertion of the magnet; an equal rush in the opposite direction accompanied its withdrawal. The magnet, for example, must not be passed quite through the coil, but only half through, for if passed wholly through, the needle is stopped as by a blow, and then he shows how this blow results from a reversal of the electric wave in the helix.

Faraday now turned the light of these discoveries upon the darkest physical phenomena of that day. Arago had discovered, in 1824, that a disk of non-magnetic metal had the power of bringing a vibrating magnetic needle suspended over it rapidly to rest; and that on causing the disk to rotate the magnetic needle rotated along with it. When both were quiescent there was not the slightest measurable attraction or repulsion exerted between the needle and the disk; still when in motion the disk was competent to drag after it, not only a light needle, but a heavy magnet. The question had been probed by Arago and Ampere but no cause could be assigned for so extraordinary an action. Faraday always recommended the suspension of judgment in cases of doubt. "I have always admired," he said, "the prudence and philosophical reserve shown by M. Arago in resisting the temptation to give a theory of the effect he had discovered, so long as he could not devise one which was perfect in its application, and in refusing to assent to the imperfect theories of others." Now, however, the time for theory had come. Faraday saw mentally the rotating disk, under the operation of

the magnet, flooded with his induced currents, and from the known laws of interaction between currents and magnets he hoped to deduce the motion observed by Arago. That hope he realized, showing by actual experiments that when his disk rotated current passed through it, their position and direction being such as must, in accordance with the then known laws of electro-magnetic action, produce the observed rotation.

Introducing the edge of his disk between the poles of the large horseshoe magnet of the Royal Society, and connecting the axis and the edge of the disk, each by a wire with a galvanometer, he obtained, when the disk was turned round, a constant flow of electricity. The direction of the current was determined by the direction of the motion, the current being reversed when the rotation was reversed. He now states the law which rules the production of currents in both disks and wires, and in so doing used for the first time a phrase which has since become famous. In 1831, Faraday for the first time called these curves, formed by iron filings over a magnet, "lines of magnetic force;" and he showed that to produce induced currents neither approach to nor withdrawal from a magnetic source, or center, or pole, was essential, but that it was only necessary to cut the lines of magnetic force.

Faraday wondered whether the rotating earth does not generate induced currents as it turns round its axis west to east. In his experiment with the twirling magnet the galvanometer wire remained at rest; one portion of the circuit was in motion *relatively to another portion*. But in the case of the twirling planet the galvanometer wire would necessarily be carried along with the earth; there would be no relative motion. What must be the consequence? Take the case of a telegraph wire with its two terminal plates dipped into the earth, and suppose the wire to lie in the magnetic meridian. The ground underneath the wire is influenced like the wire itself by the earth's rotation; if a current from south to north be generated in the wire, a similar current from south to north would be generated in the earth under the wire; these currents would run against the same terminal plate, and thus neutralize each other.

This influence appears inevitable, but Faraday's profound vision perceived its possible invalidity. He saw that it was at least possible that difference of conducting power between the earth and the wire might give one an advantage over the other, and thus a residual or differential current might be obtained. He combined wires of different materials, and caused them to act in opposition to each other; but found the combination ineffectual. The more copious flow in the better conductor was exactly counterbalanced by the resistance of the worst. Still, though experiment was thus emphatic, he would clear his mind of all discomfort by operating on the earth itself. He went to the round lake near Kensington Palace and stretched 480 feet of copper wire north and south over the lake causing plates soldered to the wire at its ends to dip into the water. The copper wire was severed at the middle, and the severed ends connected with a galvanometer. No effect whatever was observed. But though quiescent water gave no effect, moving water might. He therefore worked at London Bridge for three days during the ebb and flow of the tide, but without any satisfactory result. Still he urges: "Theoretically it seems a necessary consequence, that where water is flowing there electric currents should be formed. If a line be imagined passing from Dover to Calais through the sea, and returning through the land beneath the water to Dover, it traces out a circuit of conducting matter one part of which, when the water moves up or down the channel, is cutting the magnetic curves of the earth, whilst the other is relatively at rest. . . . There is every reason to believe that currents do run in the general direction of the circuit described either one way or the other according as the passage of the waters is up or down the Channel." This was written before the submarine cable was thought of and Faraday once informed John Tyndal that actual observation upon that cable had been found to be in accordance with his theoretic deduction.

We have heard much of Faraday's gentleness and sweetness and tenderness. It is all true but it is very incomplete. You cannot resolve a powerful nature into these elements, and

Faraday's character would have been less admirable than it was had it not embraced forces and tendencies to which the silky adjectives "gentle" and "tender" would by no means apply. Underneath his sweetness and gentleness was the heat of a volcano. He was a man of excitable and fiery nature; but through high self-discipline he had converted the fire into a central glow and motive power of life, instead of permitting it to waste itself in useless passion. Faraday was not slow to anger but he completely ruled his own spirit and thus, though he took no cities, he captivated all hearts.

The contemplation of Nature and his own relation to her produced in Faraday a kind of spiritual exaltation which made itself manifest. His religious feeling and his philosophy could not be kept apart, there was an habitual overflow of the one into the other.

Whether he or another was its exponent, he appeared to take equal delight in science. A good experiment would make him almost dance with delight. He wrote in November 1850:

> "I hope some day to take up the point respecting the magnetism of associated particles. In the meantime I rejoice at every addition to the facts and reasoning connected with the subject. When science is a republic, then it gains; and though I am no republican in other matters, I am in that."

In 1831 or 1832 Faraday was compelled to decide whether he would make wealth or science the pursuit of his life. After the discovery of magneto-electricity his fame was so noised abroad that the commercial world would hardly have considered any remuneration too high for the aid of his abilities. He called commercial work "professional business." During 1830 he had added to his income more than a 1,000 pounds, and in 1831, a still greater addition. An examination of his accounts showed that from his professional business he secured in 1832, instead of 5,000 L. or more, 144 L. 9 s. From this it fell with slight oscillations to 92 L. in 1837, and to zero in 1838. From the end of 1845 to his death in 1867, Faraday's annual professional business income was zero.

The outward and visible signs of fame were of less account to him than to most men. Twice he was offered the presidency

of the Royal Society and twice he refused the honor saying, "I must remain plain Michael Faraday to the last. If I accepted the honor which the Royal Society desires to confer upon me, I would not answer for the integrity of my intellect for a single year."

Considering the enormous strain imposed on Faraday's intellect, the boy-like buoyancy even of his later years was astonishing. He was often prostrate, but he had immense resiliciency which he brought into action by getting away from London when his health failed. He brooded on magnetic media and lines of force; and the great object of the last investigation he ever undertook was the decision of the question whether magnetic force requires *time* for its propagation. How he proposed to attack this subject we may never know. But he left some beautiful apparatus behind—delicate wheels and pinions, and associated mirrors, which were to have been used in the investigation. But the work was too heavy for his tired brain. It was long before he could bring himself to relinquish it, and during the struggle he often suffered from fatigue of mind.

Nature, not education, rendered Faraday strong and refined. A favorite experiment of his own was representation of himself. He loved to show that water in crystallizing excluded all foreign ingredients however intimately they might be mixed with it. Out of acids, alkalis, or saline solutions, the crystal came sweet and pure. By some such natural process in the formation of this man, beauty and nobleness coalesced to the exclusion of everything vulgar and low. He did not learn his gentleness in the world, for he withdrew himself from its culture; and still there was no truer gentleman than he. Not half his greatness was incorporate in his science, for science could not reveal the bravery and delicacy of his heart.

In 1840 he began to feel the effects of the mental strain to which he had been subjected for so many years. During these years he repeatedly broke down. His wife alone witnessed the extent of his prostration. He found occasional relief in a theatre. He frequently quitted London and went to Brighton and elsewhere, always choosing a situation which com-

manded a view of the sea, or of some other pleasant horizon, where he could sit and gaze and feel the gradual revival of the faith that

> "Nature never did betray
> The heart that loved her."

But very often for some days after his removal to the country he would be unable to do more than sit at a window and look out upon the sea and sky.

As his condition became more serious he went to Switzerland. His fire was now low and his strength distilled away; but the residue of his life was neither irritability nor discontent. He was unfit to mingle in society, for conversation was a pain to him.

Faraday received not less than 95 honorary titles and marks of merits; and to the end of his life he could say what he said to Mr. Spring Rice in 1838, when he was asked why he received a pension. What were his titles? He answered, "One title, namely that of F. R. S., was sought and paid for; all the rest were spontaneous offerings of kindness and good-will from the bodies named."

The first requisite of the intellectual life of Faraday was the independence of his mind and though prompt to urge obedience where obedience was due, with every right assertion of manhood he intensely sympathized. Even rashness on the side of honor found from him ready forgiveness, if not open applause. The wisdom of years, tempered by a character of this kind, rendered his counsel peculiarly precious to men sensitive like himself.

Michael Faraday was the greatest experimental philosopher the world has ever seen. The progress of future research will tend not to dim or to diminish, but to enhance and glorify the labors of this mighty investigator.

THE WESTINGHOUSE COMPANY AND ITS MEN

By F. A. Merrick

Vice President and General Manager, Westinghouse Electric and Manufacturing Company

July 7, 1928

As applied to the Westinghouse Electric Company the title "Westinghouse and Its Men" may be considered as highly tautological because the Westinghouse Company more than any other has always been the reflection of the men who have composed its organization.

Its inception arose in the brain of one man, George Westinghouse, who at once visualized its possibilities and its future and made the dream come true. His first care was to surround himself with the men who could both see and do in the wonderful new field then lying before the world ready for development.

And as we all know, the fullest development of the electrical field was made possible by the development of the alternating current, the succesful advocacy of which, in face of much initial misguided opposition, has been the great contribution of Westinghouse to the industry.

To attempt a list of all the able lieutenants who aided in this work would be impossible, but perhaps it would not be considered at all invidious to mention the names of Scott, Shallenberg, Schmidt, Tesla and Lamme. There have always been men of outstanding accomplishment in the Westinghouse Company, and its traditions insure that there always will be.

And by the way in using the term "men" this must be taken in its generic sense. The Company has had and has now women who make their equal contribution to engineering progress of the day. For example, for years one of the best of our electrical designers of large electrical apparatus was a woman, and in quite recent days a woman has supplied the best known design for securing the large blading in the rotating element of steam turbines.

You will notice, no doubt, that I am speaking of men and women whose accomplishments are in the engineering field. This is doubly prompted by the fact that the outstanding task of the Westinghouse Company has always been the one of leading in engineering conception and application, and by the fact of this being a gathering of engineering teachers.

It is by way also of a grateful acknowledgment of the fact that so many of Westinghouse men of the past and present, as will be the case with those of the future, are passed through the preparing and developing process of sitting at the feet of learning as personified in the gathering here before us.

While the schools must always be the main recruiting field, I cannot help remarking here that we have in the Westinghouse Company, both in its electrical work and in its prime mover work, engineers of nationally acknowledged standing who have never seen the inside of a university in their days of training.

This, of course, is no argument that a college training is not highly to be appreciated and striven for in the best form obtainable, but it serves to show that recognition of ability and its advancement in the Westinghouse Company is based on merit aside from any *pro forma* stamps put on a man.

George Horace Lorimer in his "Letters of a Self-Made Business Man to his Son" remarks that colleges do not make fools, but merely develop them. But he justly goes on to remark that they do the same thing for the young man who is not a fool—namely, develop him, with results highly desirable both to that young man and to the community.

In this development stage in which we are interested as a company seeking material to build the Westinghouse organization, and you are interested as the designers and suppliers of the training to fit the young man for successful prosecution of his duties, it has to be recognized that we are dealing largely in the fundamentals rather than in specializations.

The problem is to give the student his mental tools for later work and in so doing to train his mind for exact determination of facts and in logical deductions—to give him such an insight into things broadly within his field of future interest as will

enable him to choose with some discretion his future line of progress, and with a realization that the job of perfecting lies ever in the future.

Add to these the insistence on thoroughness until it becomes a habit, and a realization of the necessity of team work and loyalty in an organization, and the preparatory ground is well covered.

The rest, with a healthy body and a healthy mind, depends on how well the young man follows his training—or rather expands it into the broader field of life's actualities.

This summary is based on two thoughts—one that no man can be made in a hothouse or laboratory—it takes the touchstone of commercial requirements to furnish the final training; and the other is that not all engineering students follow engineering or research in after life.

In a business such as that of the Westinghouse Company where the whole activity is based on engineering, there are requirements for an engineering education and understanding in all divisions of the work, so that an engineering graduate finds himself likewise possessed of an excellent foundation for the work of sales, manufacturing or administration, should his other qualifications indicate best adaptability in these directions.

In fact, it is one of the recommendations of an engineering education that it is such an excellent introduction to successful prosecution of whatever work a man may in after life meet. This is because it trains to correct securing of basic facts and of uncompromising reasoning therefrom.

It is peculiarly fitting that this summer gathering of engineering teachers should be staged where there is an opportunity not only for the members of the school to contact with each other in exchanging ideas on the many problems of engineering education, but also to observe to a certain extent the conditions under which their product—the engineering graduate—finds himself after leaving their hands—how well he is fitted to function to best advantage, and how if possible his university training may be modified to serve better the ultimate progress of the man and the good of the industry and of the community.

Aside from this, we as a Company welcome the opportunity to learn from you something helpful in improvement of our training courses, and in general our handling of the graduate as he comes to us.

And then beyond all these things we are glad to have you with us as good fellows, and we trust that you will enjoy your contacts with us as much as we look forward with pleasure to your visit.

THE ENGINEER AND RESEARCH

By S. M. Kintner

Manager, Research Department, Westinghouse Electric and Manufacturing Company

July 7, 1928

I once enjoyed the title of Professor, and I say enjoyed advisedly, for my work was quite a pleasure to me until one day I undertook to read a paper presented by Peter Jungersfeld of the Chicago Edison Company in which he described a number of appliances used in that system. I was unable to understand the main points of his paper for I did not appreciate the need of these several devices for the particular service that they accomplished, let alone the description of the appliances themselves. This brought me to the sudden realization that electrical engineering practice and development were not made in the classroom. I decided to get out on the firing line by seeking employment in one of the large manufacturing companies or in the field of operation, and sought my friend Professor C. F. Scott, who was then Chief Electrician of the Westinghouse Company and who also was a trustee of the University of Pittsburgh. Professor Scott promised to help me but confessed to a feeling of embarrassment in his double capacity and I have often wondered whether this feeling was occasioned by the thought that he was taking from the University something of value or loading upon the Westinghouse Company a gold brick.

I joined the forces of the Westinghouse Company in 1903 and had an opportunity of learning first-hand of the many new things that they had in process of development. Mr. Lamme had just introduced his single-phase railway system, and after studying the causes and the remedies for the troubles that were induced in parallel telephone and telegraph lines by the alternating current trolleys and studying the electrolysis effects of the return current from the trolleys, I was given charge of the design of the single phase railway motor. I was exceedingly fortunate in being taken under Mr. Lamme's wing and having his personal direction in the design of these motors and, very much to my surprise, I learned that all of the things I had learned in my college course were insufficient to enable me to produce a design. There was no set formula that could be employed to pick out at once the final proportions of a machine. It was necessary by a series of trials and calculations of the performance of each of these machines to choose in this manner what seemed to be the best for the purpose. I recall that I was glad that there was a standard track gage because that gave one limit that reduced the number of possible combinations that I had to calculate. But very shortly someone designed a jackshaft and side rod locomotive drive which removed even this standard gage track limitation. I soon learned that experience was the most important factor controlling an engineer's design and that an engineer was an individual who put together certain combinations of elements for a factory to build. It was not necessary that this particular combination should be the last word, provided it was competitive in performance and price. This condition, however, could not remain for long because the competitor would immediately start to improve his product and then the struggle began.

The engineer limited to his experience would not be able to go very far from the beaten path and could not therefore be expected to produce anything radically different. This involved the need of an additional worker who could examine critically the elements of the engineer's design and tell him in what way he could go to extend his limits and improve his

design. This brought into existence the research worker who dissected these various pieces of apparatus and examined most minutely and critically each element to learn of the possibilities of improvement.

It is not possible for the engineer to do this research work himself. This is for two reasons. First, he is too busy with his regular designs, keeping the shop advised of changes or keeping the field advised regarding difficulties that may be experienced in their operation, to enable him to give the necessary undivided attention that is required for a successful study of these elements. Second, he is unqualified by his training to go into the necessary fields of study that are certain to be involved in a complete understanding of such a mechanism. For instance, it is not unlikely that he might be called upon to go into a study involving knowledge of organic chemistry or of some abstract metallurgical problem or even some difficult problem of mechanics, all beyond the scope of his college training. It is at this point that the scientific worker finds a place in the picture, because he by his training can make an examination of similar parts or similar problems involved in a number of different mechanisms controlled by a number of different designers.

In our work we use such highly trained specialists and assign them problems. In this assignment we not only state to them the problem that is to be solved but insist that they get in contact at once with the designing engineers who are interested in the solution of such problem. This invariably results in a much better understanding on the part of the worker and gives him a much truer appreciation of the points to be observed as of greatest interest to the designer and enables him to attack his problem much more intelligently than he would without such a discussion. As the work proceeds and obstacles are encountered, the research worker goes back to the designing engineers and again discusses with them the progress he has made and the difficulties he has encountered and the group talk the matter over and decide on the most promising way of procedure. This entire practice accomplishes two very desirable things. First of all it gives the

research worker the necessary contact with the design engineer to get a true appreciation of the problem that he is attempting to solve and, second, it makes the design engineer fully acquainted with the work that is being done, with the progress that is being attained and with the results that are secured long before the worker has completed his undertaking. In this manner the designer is made much more sympathetic with the effort than he otherwise would be. It insures the utilization of the results. Whereas, if the research worker had completed what he thought was the important problem to be solved and had taken his results to the designing engineer, the chances are that the results would be neglected because of some statement of the research worker that the engineer would recognize as wrong or which he might misinterpret. As a result of this, he would completely discredit all that the research worker had done. The other method of cooperative work makes the designing engineer feel a responsibility of it and insures the fullest possible utilization of it.

It is difficult to get the specialists who come to us from the colleges to realize that this cooperation is essential to their success. I try to drum into them the fact that a work accomplished that is 100 per cent useful but only 10 per cent theirs is worth very much more to both the company and themselves than work that is 100 per cent theirs and only 10 per cent useful.

A large industrial organization can afford the luxury of specialists of the highest training only because they can utilize them to the fullest extent. These men act as walking encyclopedias and help each other in the solution of the problems they encounter. It is not to be expected that one man will know all that is to be known, but by this method of consultation and stimulation it becomes possible to take full advantage of the advanced knowledge that each of these men has regarding a limited subject by passing it on to the other investigator so that he can come to a correct solution of his problem in the shortest possible time and most economically for himself as well as for the Company.

Perhaps you, as teachers of engineering, will be interested

in our experience with different kinds of men that are employed for research work. Let me say that it has been my experience that we secure the most desirable results from men who have been given a preliminary enginering training. Such men seem to have a better vision and a truer appreciation of what they are undertaking to do. They very generally, however, encounter limitations in their training which make it impossible with their bachelor's degree training to carry on the work to the extent that it is necessary to go. This means, therefore, that to be most useful they must take additional training to extend their knowledge along the lines of their specialty and with that thought in mind our management has very generously consented to the practice of selecting a limited number of men and sending them away to educational institutions for additional advanced training along their special lines.

If we consider for a moment the man who comes to us as a specialist with the additional college training before practical experience, we find an individual who is quite likely to have a very high opinion of his position in science and who regards his understanding of a number of the abstract scientific phenomena as giving his judgment a place much higher than it is entitled to be rated. This generally results in a lack of understanding between this individual and the designing engineers with whom he must work; the designing engineers are very prone to look upon him as a highbrow and are always looking for false statements, or at least statements that can be twisted so as to discredit him. This introduces a condition that is very difficult to overcome for sometime, even though the man may do most excellent work. This condition is quite likely to introduce a barrier that is difficult to overcome. It greatly interferes with the full cooperation between the research worker and the designing engineers for a considerable period, if not for all time, and it is with exceedingly great difficulty that the man with the advanced scientific training but little practical knowledge can worm his way into the confidence of the designing engineers and place himself in the proper relations with them.

Mr. Rugg has called attention to the important place that the engineer occupies in the world today, and I want to second this expression. As a result of the engineer's activity we have greatly reduced the working hours and in all probability will still further reduce them. The problem of what to do with the spare time then arises. Will it be utilized in useful study which is so important to the continued prosperity of our country? There is always the danger that this time will be wasted or that it will even involve the inciting of riots and other foolish things. Most certainly the engineer has given us ways of vastly increasing our country's wealth; our problem now is how to distribute it. It is my thought, therefore, that the engineer in training should be given some knowledge of economic and social conditions, because he has created a condition which will result in pulling down the house on his head unless he takes hold and sees that the extra wealth and the extra time are expended in proper manner.

APPLICATION OF ECONOMIC PRINCIPLES TO THE DESIGN OF ELECTRICAL EQUIPMENT

By A. M. Dudley

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July 11, 1928

One of the fundamental ideas which we as factory engineers wish to convey to the teachers of engineering during this group of conferences is the breadth of the job of the designing engineer. For this reason I wish that Mr. Hellmund's lecture on "Fundamental Principles in Design" had preceded mine. In it he has shown vividly how the skill of the designer underlies all of our corporate effort.

As evidence of the breadth of training gained from design work, I submit the list of twenty-three Westinghouse lecturers in this course. They represent five distinct lines of the Company's activities, viz: executive, manufacturing, commer-

cial, personnel and engineering. Under engineering are covered the three fields of research, design and application. Of these twenty-three men in these widely diversified fields, eleven have seen service as designing engineers. It must therefore follow logically that a consideration of any phase of the designing engineer's work involves all phases of the Company's activities. Particularly is this true of the economic phase, since in the final analysis the sum total of all these activities must show a favorable balance on the financial statement. With this conception I have treated my subject as being much broader than merely the most favorable labor and material content which goes into individual pieces of apparatus.

Just as this economic urge is felt more keenly by the practicing designer than by the student still in school, so we find varying degrees of its recognition among designers themselves. The engineer who is laying out a new line of machines to supersede an old one is keenly interested in producing it for the lowest factory cost, but he in turn may borrow his details, such as coil construction and bearings and commutators, from the designer of renewal parts who is in daily competition with the market on parts rather than complete machines.

In general, the results of study of economic conditions should be reduced factory cost of apparatus. By the term factory cost is meant the sum of three elements: labor, material and indirect factory expense. The third term is sometimes called overhead or burden, and includes such items as supervision, light and heat, depreciation of tools and similar expenses in the manufacturing department.

The fundamental separation into labor and material immediately introduces an economic question as to where to balance labor savings at the expense of material and vice-versa. An example of this might be a casting made heavy to minimize molding labor, or hand layout operations permitted on pieces with limited production to save the cost and investment in jigs and fixtures. It will be seen that there is a wide variety in questions of this nature.

Before proceeding to the design of the apparatus itself,

some more general problems of an economic nature suggest themselves.

Operating Problems. From the users' point of view two important considerations are investment and power cost. The first of these is not so innocent as it may appear. I remember quite forcibly a contract for 25,000 KW. in transformers which was awarded to the successful bidder because he guaranteed 99.4 per cent efficiency as against his competitor's 99.3 per cent. The additional 0.1 per cent losses were iron losses and were capitalized at $200 per kilowatt, which amounted to a total of $5,000, or in the neighborhood of 15 per cent of the price of the job. On the same basis of consideration, copper losses are capitalized at perhaps $100 per KW., which means that a penalty of 0.75 per cent in iron losses amounts to the entire selling price of the machine and a 1½ per cent lower efficiency due to copper losses would have the same result. Some food for thought for the designing engineer!

Selling Problems. Almost all economic problems are selling problems at the end, but some have a direct bearing. For example, how strong a selling argument is quality and how much better performance or longer life or more satisfactory operation can the designer afford to put into his apparatus and still meet a market price set by cheaper and less responsible competition? A part of this depends on the ability of the commercial department to convince the purchaser that these additional values actually exist and that economically he is justified in paying a higher price to secure them. The matter of appearance itself is one of the important but intangible economic factors that the designer must consider. A smoother surface or a more pleasing line or a more attractive finish can often be secured at the expense of additional labor or material in finishing. Just how far to go so that competition will be met both on appearance and price involves an agreement between commercial and engineering departments based on the various economic factors involved. A further commercial consideration is the one of publicity. Given an old, established concern and a line of equipment well known to the

trade and advertising almost reduces itself to promoting goodwill for that particular institution because of its reputation for quality, fair dealing and good service. On the other hand, assume that a new line of equipment is to be brought out which is a radical departure from known practice as to appearance, construction or function. Immediately, an economic question arises as to whether the advantages of the novel features more than offset the known expense for publicity in overcoming sales resistance to the new thing by conservative purchasers. That this is a very real thing is established by thinking, for example, of air cooling of automobile engines as against water cooling, or four-wheel brakes, or eight cylinders on the engines. Very considerable sums of money have been and are being spent to prove their advantages. An electrical parallel arose when single reduction railway motors were proposed instead of double reduction and will be encountered again in establishing the merits of proposed systems using modern improved double-reduction gears.

Engineering and Manufacturing Problems. From the rather general references which have been given to the economic conditions established by the purchaser and by the commercial department, it can be seen that at every turn and in connection with every department, be it production, manufacturing, inspection, testing, purchasing, service, accounting or what have you, the designing engineer finds himself face to face with the question of getting the most for his dollar and in the long run designing apparatus which can be built at a cost, sold at a profit and give satisfaction and life in service. In fact, these questions start with the very conditions under which the engineer finds himself working. For example, what is the most efficient form of organization for an engineering department and how are draftsmen and clerks best related to engineers for minimum operating expense? Also, is it better to have each engineer give a strict accounting of the time spent against each order or to distribute the total engineering expense at the end of stated periods in a manner which will charge a reasonable proportion to each class of work? Again, how many draftsmen

should be required per engineer and what proportion of total engineering expense can be justified as spent in estimating and negotiating business which is never secured?

Taking it for granted that these questions have been answered reasonably, that the engineering organization exists and that the engineer is ready for his job, the best idea of the economic problems from that point on can be obtained by considering some of the things which come up when a new line of equipment or machines is to be put into production. There are so many of these details that I shall no doubt overlook some which will occur to you, but I can enumerate enough of them to convince you that the successful designing engineer is a very practical economist. Because I am best acquainted with induction motors, I will take an example from that line.

The Westinghouse Company, let us say, has had on the market for a number of years a successful line of squirrel cage induction motors, the mechanical parts of which were iron castings. The squirrel cage rotor bars were bolted to the short-circuiting rings and the laminations of the stator core were punched in a one-piece annular ring. The stator slots were open and the windings were of the well known diamond coil form with two coil sides per slot. Let us assume that the art and competition had advanced to a point where this line of motors, while eminently satisfactory in mechanical operation, long life and minimum repairs, it no longer had high enough efficiency and power factor and it contained too much material and labor to be sold at a reasonable margin of profit. What then are the economic pros and cons? Some of them are: cheaper mechanical parts can be made on certain ratings by changing from castings to members of pressed steel. This change involves heavy presses and expensive dies to produce the parts. Where have we a shop which can house the necessary equipment? Is it in a locality where labor of the proper training can be hired to do the work? Will the volume of production be great enough on these ratings to justify the original cost and interest on the investment for the tools which are required? How expensive will it be to overcome the es-

tablished use of castings for this purpose and to educate the market to the advantages of pressed steel? Will such a line of mechanical parts yield itself readily to the assembly of machines with special features, such as vertical shaft, back-geared, enclosed, etc., as will castings? How will the question of renewal parts on the old line be taken care of and will it be necessary to provide storage space indefinitely for all the old patterns and formers and jigs and fixtures for the old line as well as the new, or is there some hope that repair parts for the old line might be made from the tools for the new? One of the most frequently renewed parts are the stator coils—is there any better way to make them than on the old wooden moulds? (From the last thought is born the idea of the so-called pulled coil which requires only a simple straight shuttle instead of the old expensive and cumbersome iron-bound wooden mould.)

Thinking next of the power factor and efficiency, the designer realizes that he can improve these materially and also cut down the material in the machines by reducing the air gap or rotating clearance between the stator and rotor and also by making the stator slots partly closed instead of open. But unfortunately there is a strong prejudice against small air gaps and a stronger prejudice against windings in closed slots. So a careful economic balance must be made of sales resistance on one hand and improved performance and reduced cost on the other. Again it appears that by taking advantage of a new type of punch press recently developed, the punchings for the stator can be made more cheaply from segments than from complete circles, owing to greatly reduced scrap. But this requires more machining of the frame, more exact workmanship and more labor in assembling—result, another economic study to balance these conditions.

Next comes a careful study of sizes of wire and rectangular conductors to be used for winding the coils of the complete line. The fewer sizes of special conductors that are used, the less will be the stock to be carried and probably also the lower will be the cost per pound. A study of bolts and screws and drills and taps to be used must be made so that one size may

be used throughout a machine if possible; also care must be used that sizes of materials and of drills and taps come in a preferred number system, if possible, because in this way in a large establishment great economies can be made.

When it comes to the actual design, numbers of slots must be chosen which will cover the greatest possible number of phases multiplied by poles, because requests will be received for motors with special speeds which must be built on the same punchings. The sizes of shaft extensions and keyways must be chosen to fit the maximum number of conditions. The number of problems of this nature all involving economic considerations could be quoted *ad lib* even introducing the human element, such as designing so that women could be used in various operations instead of men at a somewhat lower rate.

Assuming that design and tooling questions are settled, inspection specifications must be written so as to catch imperfect work without throwing out parts on technicalities which really do not affect quality. Many hours does the designer spend arbitrating questions of material and workmanship between the production man who is interested in "how fast" and the inspector who questions "how good." Next the matter of testing comes up—how many units from production shall have complete curve tests and what shall be a reasonable commercial test to insure quality? All these questions, you will note, involve an immense amount of common sense and judgment to insure the happy general result of a contended user and a satisfied stock holder. That is why a designing engineer, if he weathers the storm and assimilates his experience, develops into an executive. It is because he has been finding in less degree the answer to a host of economic questions which *in toto* are the executive's responsibility.

Along with inspection and testing goes purchasing. Here is a chance to make and lose money at a startling rate—To buy materials of the right quality on a reasonable specification; to buy market standards and avoid specials; to have the right number and right kind of suppliers without spending time and money to test the products of each concern with high pressure salesmen demanding attention; to buy always

the right quality that goes with the job and pay a fair price for it—these are questions which require a high grade of economic analysis; they cannot be settled by the buyer alone. The designer and the material and process engineer get good training on economics in this field. At this point comes the balance between using a higher priced material and using less of it as against an apparently cheaper one that costs more in the end. An example of this is high grade silicon steel. There are many designs where its total cost is less than ordinary mill annealed steel because of its effect in decreasing iron losses.

After all these questions are fairly settled, the question of finished stocks comes in for consideration. What ratings and how many shall be carried? What parts can be carried and assembled into different combinations? How can machines be carried and sold for either 220 or 440 volts and what is involved in reconnecting in the store house? Where shall the finished stocks be carried to minimize freight? When one considers that there are in America three standard frequencies, five standard voltages up to 200 HP., two standard polyphase systems, pole numbers from 2 to 14 or more, and horsepower ratings from 1 to 200 in at least 13 steps, the number of permutations and combinations is appalling. When to this is added the thought that many may be called for vertical or back-geared or enclosed or dust-proof or acid resisting, the real reason appears why the designing engineer is a shrewd analyst of economics. He must both analyze the combinations most frequently used and he must devise means for meeting these combinations with the minimum investment in part and finished stocks.

This is by no means a complete treatise but is intended to be suggestive in teaching in two ways:

1. To show that the job of the designing engineer is much broader than making calculations and supervising drawings and,
2. That the consideration of economics begins with the first piece of material and the first manufacturing opera-

tion on it and runs throughout the history of the apparatus until it has been finally junked and sold as raw material from which a new designer will build a new machine to meet a new set of economic conditions.

FUNDAMENTAL PRINCIPLES IN THE DESIGN OF ELECTRICAL EQUIPMENT

By R. E. Hellmund

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July 20, 1928

Since all the papers presented before this conference are intended to deal with the subject of teaching, I assume that it is appropriate for me to outline some of my thoughts regarding the teaching of the design of electrical equipment and the fundamental principles relating thereto. I trust that it will not be considered presumption on my part if I, without experience in teaching as it is practiced in the schools, try to make some suggestions to a body of men experienced in this art. I also hope that you will bear with me if, on account of my unfamiliarity with the details of all the courses as they are now given in the many American universities, some of my statements may reflect lack of complete information on American procedure. But even if such should prove to be the case, I believe that my remarks will prove of some interest to you inasmuch as they are the reaction and result of my rather close contact with a large number of engineering graduates (over one hundred annually) and the rather extensive teaching program carried on by the Westinghouse Company in connection with these graduates. The design of any equipment, electrical or other, is in the last analysis nothing but the *application of fundamental principles* of the laws of nature to the *creation* of equipment which is to be *useful to humanity*. In other words, "design" is a very broad activity, and consequently a designer must have a very broad

point of view; so in using the term "designer," I use it in its broadest sense. The designer is the engineer who conceives the equipment and who is fundamentally responsible for it in every respect. He is responsible to the shop, which builds it as a consultant, to the sales organization and to the final user; his responsibility does not cease until the equipment is an engineering, manufacturing and commercial success and until it has served its natural period of usefulness.

It is at once evident from the definition of design as given, that the teaching of fundamentals to future designers is most important. This fact has been realized for quite some time and greatly stressed in many discussions on the teaching of engineering. In fact, the teaching of fundamentals has been stressed to such an extent that some representatives of the industries, as well as some teachers, have suggested that the schools limit themselves almost exclusively to the teaching of fundamentals, leaving it to the industries to educate the men later on in their particular design and working methods. Such a suggestion is largely prompted by recognition of the fact that it is impossible for any school during a four-years' course to cover, in addition to the fundamentals, their application to the design of the numerous types of equipment entering into electrical engineering work. Although I fully appreciate the latter difficulty, nevertheless I feel that the teaching of design should form a very important part of the curriculum. For this I have a number of reasons.

In the first place, the mere teaching of fundamentals, or in fact any teaching which imparts knowledge of any kind to the student, develops in him principally a habit of study and a capacity for absorbing. Now, according to our previous definition, design is primarily the art of creating something, and the knowledge acquired through the study of fundamentals and other things represents merely the tools necessary for such creative activity. I therefore feel that it would be violating the very fundamentals of education if an engineering student, whose very life activity is to be that of creating and acting, were trained merely in absorbing during one of the most formative periods of his life.

It is frequently contended that while the schools are unable to give the student all desirable knowledge, they can and should develop in him the habit of logical and analytical thinking during whatever limited courses can be given. This statement is undoubtedly correct and it brings out the fact that the forming of proper habits is an essential part of any educational system. This being the case, it seems obvious that in the education of an engineer, whose future work is to create, the development of his individuality and the habit of creative thought and action should be carefully cultivated.

My feeling that engineering schools in their present curricula do not sufficiently stress training in actually doing things is borne out by practical experience. Too many cases are apparent where men with excellent school training and good fundamental knowledge lack the necessary initiative, originality, and ability to get things done. As a result, they continue to occupy mediocre positions, while men with less education but with a capacity for accomplishment gleaned from the school of life step ahead of them.

With the previously discussed fundamental considerations before us, the question arises as to what can be done to take account of them properly in our teaching plans. Before trying to answer this question, however, let us briefly review the present typical curriculum of engineering schools. We find they may cover the following fundamental studies: mathematics, physics, chemistry, mechanics, direct current and alternating current theory, economics, and psychology. All of these I consider of greatest importance in connection with electrical design.

The need for a great deal of mathematics, physics, direct current and alternating current theory in electrical design is obvious, and I believe these subjects are generally receiving all the attention that time permits. Chemistry, including metallurgy, which is usually somewhat distasteful to the average engineering student, is often neglected. It is nevertheless of great and increasing importance in connection with all materials used in electrical design. Although it is true, especially in the larger industrial organizations, that specialists

are employed to handle the subject of materials, the design engineer should know enough of the fundamentals of chemistry to keep him out of trouble and to enable him to confer intelligently with the specialists when necessary. The importance of mechanics in connection with electrical design can hardly be overestimated. I feel sure that considerably over fifty per cent of the problems and difficulties arising in the design of electrical apparatus are of a mechanical rather than of an electrical nature. One specific mechanical problem which has not received sufficient attention by the electrical designer is that of air-flow and ventilation. Economics is another subject which in the past has not received the proper attention, but there is now discussion regarding its importance and undoubtedly it will receive increased attention in the future.

The reason I am emphasizing a number of these non-electrical subjects in connection with electrical design is that the electrical designer, while making a fairly good job of his electrical problem, has done so in many cases at the expense of some of the other problems. In the development of electrical equipment, more progress now seems possible through the application of the fundamentals of such subjects as economics, mechanics, ventilation, chemistry, and metallurgy than through the application of purely electrical principles. It may be somewhat surprising that psychology also has been mentioned as one of the important fundamentals for design work. Reference may be made here to our definition of design, which states that it has to do with the creation of equipment useful to humanity. It is therefore evident that a knowledge of human nature must play an important part in design work, more especially, perhaps, in connection with the design of household appliances, but also to a large degree in the design of equipment used in the industries, transportation, and for other purposes. Aside from the fact that psychology is thus important in connection with design work as such, it has other and far broader aspects. A knowledge of it enables the engineer to understand his co-workers and makes it possible for him to accomplish things through the cooperative efforts

of others which he might not otherwise be able to accomplish. Furthermore, psychology may make him happier and more philosophic in his attitude toward life and toward his work.

In addition to the fundamental studies just discussed, the usual curriculum contains a number of specific engineering studies such as telephony, telegraphy, radio, electrical machine and apparatus theory, lighting, hydraulics, etc., all of which undoubtedly are useful and should be continued as far as time and other conditions permit. The same applies to such general studies as English. It is also customary to include a certain amount of laboratory, drawing office, and shop practice. These not only are helpful on account of the familiarity with the use of various tools and instruments which the student acquires through them, but they also fall somewhat in line with what has been previously said in that this work requires a certain amount of initiative and action on the part of the student.

I also find that the curriculum usually contains certain courses called "electrical machine design," or the like. From all the knowledge that I have gathered regarding such courses, it appears that they very frequently consist of calculating methods for such apparatus as transformers, d. c. machines, a. c. generators, induction motors, etc., all these being crowded into a rather short period of time. While I appreciate that some of these calculating methods will prove a most useful tool to the future electrical design engineer, making it desirable that some of such work be given in college, I should like to make a strong appeal that this work not be given under the name of "design," but that it be designated what it really is, namely, "calculating methods." It might also be suggested that instead of attempting to crowd too much of this work into a short period, it would be desirable to cover less ground and give the student an opportunity to cover this ground more thoroughly. Certain omissions in this connection will be quite satisfactory, because it is a natural fact that the industries can readily acquaint the young engineer with specific methods for designing the particular apparatus in which they specialize.

Assuming that the calculating work just referred to can be disposed of under its proper name as suggested, I should like to see the curriculum include an activity called "DESIGN" which would extend throughout the four years' course. This activity, according to my ideas, should not consist of the teaching of the design of any particular type of apparatus or devices, but should be intended principally to teach the student, through actual practice, the art and habit of design from a broader point of view. It may be quite logical to have such work deal with electrical equipment in the case of electrical students, although I do not consider this of prime importance.

The question may be asked—How is it possible to teach design in the Freshman year, that is, at a time when the student has not had any previous instruction at all in any of the fundamentals entering into design? I consider this very fact an advantage because it will then be possible to bring to the student's attention a number of fundamentals outside of mathematics, physics, etc., which might perhaps be designated as "common sense fundamentals," but which, however, are of very great practical importance. At the beginning of the course, it may be well to give a few short lectures setting forth some of the basic ideas of the course along the lines suggested in this discussion, and then simply to put up to the students, preferably divided into several groups, a simple design problem.

This may best be illustrated by an example. Let us assume that one of the groups is asked to design an electric flatiron. Naturally, in the beginning they do not know how to get started on such a problem, but this very fact brings strongly before them one of the main characteristics needed by designers, namely, originality and resourcefulness in tackling a proposition which is entirely new to them. They might be told that since they are not as yet familiar with engineering work, they should rely on their common sense and see whether they cannot accomplish a good deal through it. They might further be reminded that before starting their work it would be well for them to find out what already exists in this par-

ticular field. It is especially important to impress upon them the fact that it would be foolish even to start a design of their own without first having found out with what they have to compete on the open market. A study of this question can be accomplished by writing for catalogs of flatirons and by inspection of existing products at home, in the stores, or elsewhere. The students might be encouraged to find out what prices the irons sell for, which of them are the best sellers, and possibly to study the features which make them the best sellers. The psychology of the selling of such device might be studied to determine whether such an iron as the "American Beauty," for instance, is selling well on account of its attractive name or because of distinctive features; whether the Westinghouse iron is selling well because of its distinguishing feature of automatic control or for some other reason. In general it may be pointed out that while price is of importance, price itself is largely determined by distinctive and useful features. The question of appearance may be brought into the picture as an important factor, and even the methods of marketing articles of this kind might be given a certain amount of consideration. By stimulating the student in all such considerations and activities, he will appreciate the importance of studying the requirements before starting on the actual design, an activity which is too frequently neglected by many designers.

The next logical step is a consideration of the detail mechanical features and the manufacturing methods for producing the various details. After the student has been wondering about some of these things, and only after that, it might be in order to arrange for a visit to a manufacturing establishment where flatirons or similar articles are made. The student may also be referred to various books giving information on the subject matter.

I have purposely stated that a visit to the factory should be postponed until after the student has spent some time on his problem. This is because I feel very strongly that it is only after the student has been made hungry for more knowledge and confronted with the difficulty of getting at his prob-

lem that he will really appreciate the acquiring of additional knowledge. This principle, I feel, should be kept in mind constantly by teachers of design. As far as possible, the teachers should keep in contact with the entire course the student is taking and should put the problem or a specific part of it before him just a little ahead of the time at which he obtains through the lectures valuable information pertaining to his problem. It may also be very good practice to have the student take his problems to the various other teachers for help, and so stimulate the other teachers to include in their lectures material which is of direct value to the student in solving his problem. Then, too, such practice of sending the student to others for assistance may help him to realize that most engineering problems nowadays are so intricate as to require the assistance of specialists and that the practice of seeking such assistance is perfectly legitimate.

Only after previous general and broad studies have been completed is it necessary for the student to tackle the rather minor electrical problem in connection with the flatiron. He will, of course, have to know by this time, and probably does from his high school work or from his college work in physics, the ohmic law and the relation of watts and energy to the amount of heat produced. He can find the wattage used in different existing irons and figure from this his resistance and ways and means for introducing such amount of resistance into the iron. Depending on whether or not his previous study of physics makes it possible, he may also be able to determine the various relations between weight or mass and heat absorption and between surface and the cooling of the iron by radiation, conduction, or convection. This might possibly be tied in with the student's laboratory work.

In further work, it will of course be necessary for him to study various materials used in the iron, especially the material to be used for the base of the iron, for the shell, the internal weight, etc.; whether they should be forged, cast, or pressed, and many other questions of this kind.

The next best thing for him to do is to make actual sketches and drawings of all the parts. This I consider an essential

activity, because it is really only in the process of putting the results of his previous studies on paper that many questions are brought to his attention that he may previously have overlooked. In making his actual final design, the student should be made to realize that while his previous investigations and studies are useful and necessary steps in preparing for his work, he is expected, as an engineer, to conceive something new and better than anything so far devised. This can be done either by using a better combination of known detail features or by improving individual features here and there. For example, he could be reminded of the fact that inasmuch as the iron has a certain mass it takes an appreciable time to heat it ready for use, and this delay is of course distasteful to the user of the iron. The question should then be raised as to whether this delay could be shortened, particularly in the automatic iron, since the automatic switch prevents the iron from getting too hot even if the wattage of the iron should be increased. In studying this possibility, the limitations imposed by the underwriters and the reasons for these limitations should be brought out. As a second possibility for reducing the delay in heating, a smaller mass could be considered and the effect of such smaller mass and reduced weight upon the operation of the iron.

As a final touch to the entire design activity, it would be expedient to have the student make a brief and concise statement regarding the various features of his design, the reasons for adopting these features, and the advantages of his iron over others.

I hope that I have made clear how a simple problem such as the one given, will point out to the student the broad aspect of design work. Especially in the Freshman year, when his mind is not taken up too much with theoretical points, he can get a very good perspective of his problem as a whole; perhaps better than he can later in a problem more complicated technically.

From the outline given on this example, it is at once evident that considerable time will be required and that it will be impracticable to handle perhaps more than a single such prob-

lem during each college year. However, if properly carried through, I believe that one or two such design problems a year will be sufficient to accomplish the desired results. Furthermore, I believe that rather short periods of time during the weekly school sessions will be ample for the purpose, because many of the activities suggested can be taken care of by the student during spare moments and outside of school. Some of them, as previously intimated, may even be tied in with other studies and with laboratory work.

With this one example before us, it should be easy to find a somewhat slightly advanced problem for the Sophomore year and no detailed discussion of it seems necessary.

As a possible problem for the Junior year and to further illustrate some additional ideas I have in mind, let us consider the design of an oil circuit-breaker. As you know, the present curriculum, even in the Senior year, gives the student very little information specifically applicable to oil circuit-breaker design. It therefore might be well to start this problem by frankly acquainting the student with this fact and again emphasizing to him that he has to utilize his own resourcefulness together with whatever information he can get from various sources. As in the previous case, he should become familiar with the prior art and also acquaint himself with the standards set up by various engineering bodies regarding the ratings and rules applying to oil circuit-breakers. Since the college course supplies no calculating method or instructions, the value of looking up existing literature on the subject should be pointed out and some help given in locating such literature.

As the student is now further advanced in his study of fundamentals, especially physics, he should be led to utilize whatever he can of it and study such items as the extinguishing of an arc in the case of alternating currents, the importance of the arc energy in disintegrating and evaporating the oil and the pressures caused thereby, the significance of the re-ignition voltage after each cycle, etc. After the student has gone as far as he can in drawing upon all available sources of information, he should be urged to go ahead and do the

best he can in producing a commercial design. In other words, he should be made to realize that in practice it is frequently necessary to act without knowing all the fundamentals covering the design in detail. He should further be made to appreciate the value of using all fundamentals with which he is familiar, even though they do not give him complete data. For example, an inexperienced student might get the mistaken idea that the oil tank and the supporting structure need to be strong enough to support merely the weight of the oil. However, through his fundamentals, he will at least know that there is in addition to this a pressure problem to be considered, even though he may not at this time be able to determine just what such pressure is. Knowing that there is a pressure problem, he can determine from prior art what practical experience has led to in taking care of this problem. Such line of thought should bring home to the student that while his fundamentals may not tell him the whole story, they usually are very useful in guiding him and give him sufficient knowledge to keep him out of serious trouble. Again, in designing the arcing tips for the breaker, the fundamentals will tell him that there is considerable energy transferred into heat at the contacts, resulting in the melting away of such contacts under heavy shorts, and although he may not be able to figure how such contacts should be proportioned, he should know that there is a heat problem which can be taken care of by reasonably large masses of copper in the arc contacts and especially at the point where the arcing takes place.

If time permits, many other features of the design can be studied in detail, as, for instance, the operating magnets for the breaker. A good deal of mechanics can be applied in the operating mechanism. The speed of the breaker and accelerating problems can be introduced as well as the influence of electromagnetic forces during short circuits; any previous knowledge on insulation stresses can be utilized in designing the terminals; etc. It is, of course, again possible to introduce considerations of materials, among which the oil is of especial importance, of manufacturing methods, economics, etc. A visit to a factory at the proper time may again be helpful, or

perhaps if that is not possible, a trip may be made to a power plant or substation where breakers can be inspected. More or less complete drawings should then be made. Finally, inasmuch as many things about the breaker are not known, the student might be asked to make at least an outline of tests to determine the suitability of the breaker for its rating and application.

Coming to the Senior year, the student may now be in a position to undertake the design of pieces of apparatus for which more or less set calculating methods from his other studies are available. Let us assume that he is asked to design an induction motor of a given horsepower and speed. He has now learned from his previous design work to look around first and study competitive and prior art instead of starting in immediately with a lot of figures which have no meaning to him, as I know is customary in many cases at present. The study of existing apparatus is similar to that previously described, except that it may be more technical in that it includes performance data such as efficiency, power factor, pull-out torque, starting torque and current, etc. In order to study the requirements completely, the student should also be led to investigate the various applications for which the motor may be used, such as belting, gearing, direct connection, etc. If possible, a study of existing apparatus should be tied in with tests and laboratory work on whatever similar induction motors may be available, and the test results should be compared with those obtained by the calculating methods used for the design.

In carrying on these studies, the student may find that motors of some manufacturers having a given rating, are much smaller and lighter than those of others, and he should be led to analyze why this is—whether it is the result of better ventilation, better materials, or for some other reason.

This may be followed by economic considerations. Among other things, it may be pointed out that the design of a certain motor for one single rating is uneconomical and impractical, and that it is necessary to design the parts, and the expensive manufacturing equipment involved, for a number of

other ratings which can be built on the same frame or at least on the same diameter. As a result of this, the calculations may then be carried through for a number of ratings for which the greatest number of common parts may be used. This may be followed by a study of the detail parts, especially the mechanical features such as shaft, bearings, etc. Very interesting studies are possible, for instance, in connection with such parts as the shaft. Ordinary stress calculations based on the torque to be transmitted will of course give dimensions much smaller than it is customary to use. The influence of magnetic pull, belt pull, vibration set up by the gears, etc., may then be taken into consideration either by calculating methods or by merely making liberal allowances. Even a certain psychological effect can be introduced by pointing out that a shaft, if it looks too small for a given diameter rotor, although strong enough, may react against the sale of the motor.

As in our previous problems, the final work should preferably contain some new or original features. As usual, the design should be carried through in the form of drawings, and a description of the various features and the reasons for their adoption should be given, as well as an outline of the tests. All in all, the possibilities of injecting different and broader points of view in work of this kind are almost inexhaustible. The student may even be asked to consider briefly the question of stocking the motors and parts in view of the fact that the number of mechanical and electrical modifications likely to be called for are very great. In order to make the design problem of the Senior year a matter of sufficient importance in student's mind, it might very well be used as the subject of his thesis.

I have no doubt that if the student is led to handle his design problem in this broader way, very frequently he will approach his teacher with questions which the latter will be unable to answer. However, instead of being embarrassed by such a condition, the teacher should take the position that many of these questions cannot be answered offhand, but should be made the subject of study or investigation, and all

he should attempt to do is to give some helpful guidance in such study, rather than to try to answer the question directly, even if he should be able to do so.

I am, of course, fully aware of the fact that many of the suggestions made are taken care of here and there in different ways in the present curricula as adopted by the various schools and that a good deal of practice is no doubt obtained by the students in connection with certain problems now part of their various studies. However, such examples frequently are more or less of an abstract nature and cannot arouse the same interest in the mind of the student as they would if he had met them in the solution of an actual design or other engineering problem.

The thesis required by some of the schools covers some of the points I have in mind, but coming as it does in the Senior year without previous practice in such work, the results are not always the best; moreover, the opportunity given by the thesis for developing the students along the lines indicated is hardly sufficient. Again, many schools require no thesis at all, and others make it optional, with the result that but few of the students make the necessary effort.

Some of the so-called student activities prove very helpful in developing initiative and resourcefulness, but usually the limited number of students who take part in such activities are those naturally endowed with such traits, while those needing the training most do not get it. Some of the schools attempt to cover the more practical end of the student's education by cooperative arrangements. Such practice has a great deal in its favor from many points of view.

In this paper, which is intended to deal with design, I have naturally laid a great deal of emphasis on the application of certain fundamentals to the teaching of design. The same fundamentals apply, however, to most any engineering work. It may, therefore, be in order to raise the question as to whether the development of the desirable traits and habits in the student should not rather be taken care of in a broader course called "engineering problems." This, of course, might be done, but even then such course should place a great deal

of emphasis on design. Through experience, we have found it advisable to give our future application engineers rather extended design practice and I believe that the design point of view will be very helpful to operating engineers and others as well, especially with regard to certain economical features such as standardization of apparatus or parts thereof, etc.

Before closing I wish to state most emphatically that although I have stressed certain factors such as common sense, commercial considerations, etc., in what I have said, this should by no means be interpreted as meaning that in my opinion such fundamentals as mathematics, physics, chemistry, etc., are not of utmost importance and should not receive all the attention that can be given them. On the contrary, one of the main purposes of the plan of teaching design as I have outlined it is to increase the interest of the student in all his other studies and to bring home to him the fact that they all prove essential at some time or other. I am quite confident that through this means the effectiveness of the other studies will be very materially increased and that this increase alone will well pay for the limited time set aside during the entire four years' course for the teaching of design. I hope that I have been successful through my statements of fundamentals as I believe they apply to design, and through the examples discussed, in giving a fair picture of what design really is in practice. I am confident that the suggested method of teaching it will be beneficial to the student in his future activities, and, incidentally, it will help the industries, because after getting from his college work a better picture of what design really is, the student will come to the industries eager to take up design work instead of coming, as he frequently does now, with a fear and horror of spending a lifetime in slide rule and pencil pushing. But above everything else, the indicated method of teaching should develop in the future engineer, while he is still in the more formative period of his life, such traits as action, originality, resourcefulness, creative ability, and interest in and love for his future work.

MOTION PICTURES TO HELP STUDENTS IN CHOICE OF CAREERS

BY FRANCIS W. ROYS

Worcester Polytechnic Institute

An article by Professor Timbie of the Massachusetts Institute of Technology in the February JOURNAL suggested among other things, that illustrated lectures or talks by individuals from industry or from engineering societies had been used in some instances in the attempt to give students some idea of the various types of engineering activity. It struck the writer that this is a matter of very great importance and one in which the Society for Promotion of Engineering Education, as well as the professional engineering societies should be interested.

Would it not be a good idea for these societies cooperating, to plan and to produce a series of motion picture reels, which would attempt to display the field of activity of the various groups of engineering? If this were attempted, there should be a very careful explanation accompanying any such films, probably as a part of the film itself. A short lecture might be prepared to accompany each film if it were thought advisable to be used or not, as the institution showing the reels might desire.

This matter has already been called to the attention of Secretary Bishop of the Society for Promotion of Engineering Education, who has expressed his interest and at whose suggestion this article is written. It has also been called to the attention of Mr. Calvin W. Rice, Secretary of the American Society of Mechanical Engineers, who writes "The idea is excellent and I shall be glad to help make the scheme a success."

Of course there will be considerable expense involved and considerable labor in collecting, selecting and editing mate-

rial, but it seems quite probable that the professional societies will be willing to perform a great deal of this service in so far as it concerns their branch of engineering.

It would seem as if the function of the Society for Promotion of Engineering Education in this matter would be to work for the cooperation of these societies and help them to plan and to select the most effective type of pictures.

There are at present great quantities of so-called educational films, news reels, advertising films and so forth, none of which are in any way adequate in themselves, but parts of which might be used if it were known just what is wanted.

The reaction of the writer is that young men contemplating technical careers do not understand what the various branches of engineering include; what the variety of activity within each branch may offer; and what the function of the trained personnel actually is.

Such a set of films should show the mechanical engineer in design; construction; production; research; testing; sales engineering; management. It should show him in manufacture of raw material of various sorts; it should show him in manufacturing of machinery, tools, mechanical devices, but also of non-metal products, like cement, textiles, foods, etc. and his part in power development and generation. It should show if possible, how important the college training is for success in these lines. The civil engineer in bridge work, roads and pavements, railroads, sewage disposal, building construction, water supply, etc. in design, construction, operation, maintenance, etc. The electrical engineer in generation of electricity, transmission, distribution of power, communication, lighting, heating and countless other things which are not particularly familiar to the writer. Also for the chemist or chemical engineer, a similar set.

The more fundamental these films may be kept, the closer they will fit the need of the prospective engineering student. It will be difficult for those who have known and do know of all the interesting ramifications and specialties of the various branches of engineering to get the point of view of these

young fellows who do not know much about it and therein lies the danger.

Civil, mechanical, chemical, mining and electrical are entirely sufficient for a beginning; in fact if any attempt were made to prepare for much more than this, all effectiveness would be lost, for the rest are specialties build on one or the other of the above as fundamentals. If simplicity and singleness of purpose are adhered to, something worthwhile may result.

Such a set of films in high school might inspire and attract good material which now goes elsewhere and it might discourage some of the unfit material which has no aptitude for such work. Again, such a set of films for use in technical colleges shown a few weeks prior to the time for choice of course, would paint a very effective picture in the students' minds and ought to help them in the proper selection.

Surely industry and the engineering profession are vitally interested in getting the best results and in this there is nothing to be lost and there is the possibility of considerable gain.

THE COLLEGE OF ENGINEERING OF THE OHIO STATE UNIVERSITY

BY WILLIAM D. TURNBULL,

Junior Dean, College of Engineering,

AND

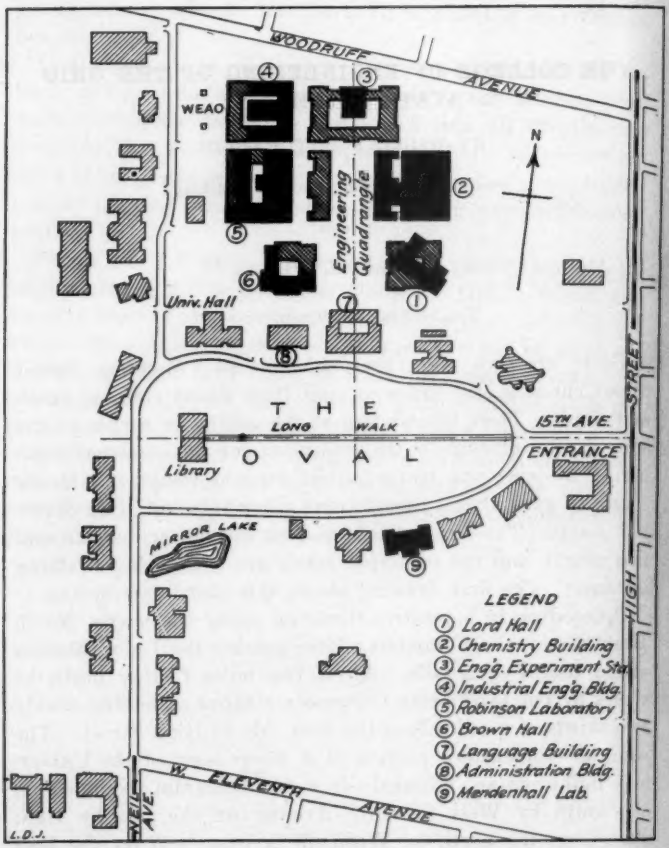
MERRILL WEED,

Engineering Experiment Station

There are two main thoroughfares in Columbus, Broad Street running east and west, and High Street running north and south. Their intersection at the northwest corner of the state capital grounds is the zero point for the residence numbering system; our mathematical friends would call it the origin of axes, Broad Street being the x-axis and High Street the y-axis. The city's chief business district centers around this origin, and the principal hotels are within easy walking distance. The first drawing shows this coordinate system.

Proceeding in a positive direction along the y-axis, North High Street, the Columbus visitor reaches the Union Station at six tenths of a mile. About two miles farther north he comes to The Ohio State University campus extending nearly two thirds of a mile along the west side of High Street. The campus—the eastern portion of it where most of the University buildings are situated—is a parallelogram, bounded on the south by West Eleventh Avenue, on the east by High Street, on the north by Woodruff Avenue, and on the west by a line a little west of Neil Avenue and parallel to High Street. The drawing shows an alternate method of reaching the campus, via the Neil Avenue car line. This trolley follows High Street past the Union Station, runs west along Goodale Park to Neil Avenue, and thence up Neil Avenue to the southwest corner of the campus.

The University's most noticeable landscape feature is the



EASTERN PORTION OF THE OHIO STATE UNIVERSITY CAMPUS SHOWING THE ENGINEERING QUADRANGLE

Completed Engineering Buildings in solid black.
Proposed Engineering Buildings in heavy section lining.
Other buildings in light section lining.

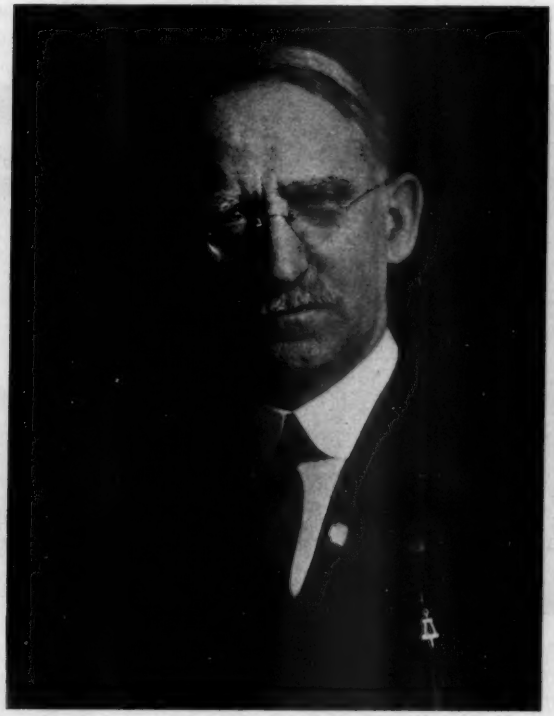
"oval," an open green, roughly elliptical in shape, and surrounded by a driveway nearly a mile long. The only building on the oval is the University Library which crowns a slight hill near the western end of the enclosure. Along the major axis of the oval a broad concrete walk, "the long walk" in student parlance upon whose sacred surface freshmen dare

BROWN HALL ENTRANCE

not tread, extends from the main entrance of the campus at Fifteenth Avenue and High Street to the Library more than a third of a mile away. The oval is the scene of parades and reviews of the R. O. T. C. brigade. Probably no other university has so magnificent a college green.

The earlier buildings of the University were distributed outside the driveway around the oval, in space which seemed inexhaustible when the school was younger and smaller. The need for additional room forced a change in the plan of de-

velopment. The present scheme is to group the buildings of each college about a court or quadrangle on an axis at right angles to the major axis of the oval.



DEAN E. A. HITCHCOCK

The engineering quadrangle, now beginning to assume definite form, is just north of the oval. The drawing of the eastern portion of the campus shows the engineering buildings and the plans for their ultimate development.

At the southeast corner of the quadrangle is Lord Hall, the

mines building, named in honor of Nathaniel Wright Lord, first dean of the College of Engineering. Lord Hall contains the departments of mine engineering, ceramic engineering, mineralogy, and metallurgical engineering, as well as the ceramic experiment station of the United States Bureau of

ENGINEERING EXPERIMENT STATION BUILDING

Standards, and, temporarily, the offices of the College of Engineering. The present Lord Hall, as the plan shows, does not fit into the quadrangle scheme; to complete the court the building will either have to be moved or torn down and rebuilt.

Proceeding about the quadrangle in a counter-clockwise direction we come next to the Chemistry Building on the east side of the court. This new structure, four stories high and 317 feet long gives an idea of the architecture of the buildings which will surround the court. Here are the offices and classrooms of the departments of chemistry and chemical engi-

neering. The laboratories, of modern saw-tooth roof construction, are located in the rear of this structure and cover nearly an acre and a half of ground.

The completed portion of the Engineering Experiment Station Building, at the north end of the quadrangle, is about one fifth the size of the proposed building. This structure was framed of steel designed for the power plant at Langley Field, and, after the War, bought by the University at a bargain. It is sturdy enough for practically any kind of research. Among the major items of equipment are the million-pound, 500,000-pound, and 400,000-pound testing machines, the fire-

LORD HALL

test furnace, and the gas laboratory with its one-ton retort. The Ohio Stream Flow Survey and the State Highway Testing Laboratory also have quarters here.

Industrial engineering and mechanics occupy the Industrial Engineering Building at the northwest corner of the quadrangle. The industrial engineering laboratories are large and

well-equipped for practice in forging, woodworking, foundry, machine shop, and other details of industrial practice. The mechanics laboratory contains testing machines for demonstration of the elastic properties of materials.

West of the quadrangle is the Robinson Laboratory, named in honor of Stillman W. Robinson, the University's first professor of mechanical engineering. Here are the headquarters

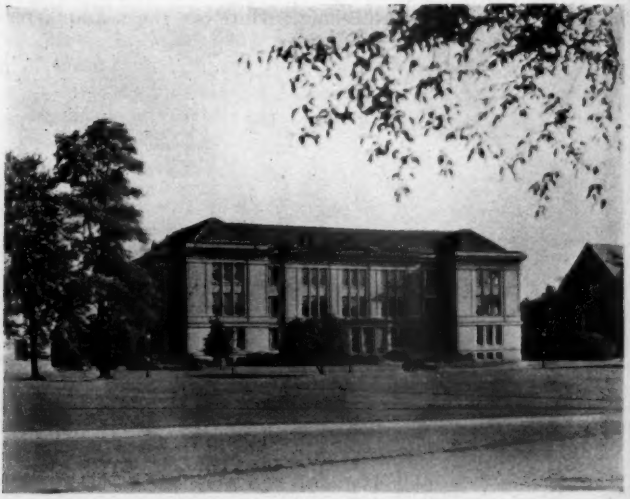
THE NEW CHEMISTRY BUILDING
(General Sessions will be held here)

and laboratories of mechanical and electrical engineering. The communication laboratory and studio of the University broadcasting station, WEAO, are in a building adjacent to the electrical engineering laboratory, and the sending station and tall aerial towers are nearby.

The plan of development calls for a long, four-story building, the counterpart of the Chemistry Building, to be constructed on the west side of the quadrangle in front of Robin-

son Laboratory. Here will be located the offices and classrooms of mechanical and electrical engineering.

The offices of the College of engineering are planned for the addition to Brown Hall at the southwest corner of the quadrangle. Brown Hall, the seat of architecture, civil en-

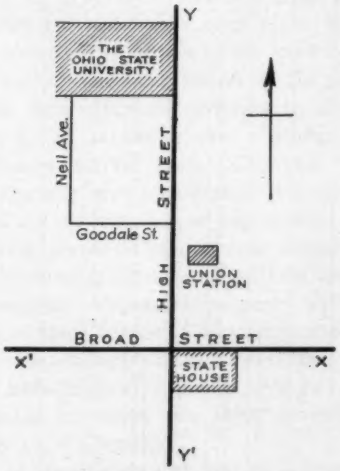


MENDENHALL LABORATORY OF PHYSICS

gineering, and engineering drawing, differs from the other buildings of the group in being constructed of buff brick. It was named for Christopher Newton Brown, for many years professor of civil enineering, and second dean of the College of Engineering.

Appropriately enough the building which closes the south end of the quadrangle and forms the bridge connecting the engineering court with the remainder of the University is the Language Building, the hall in which the engineering students will have their English classes. This structure is rapidly nearing completion and will probably be used in the fall of 1929.

This survey of the engineering group shows that the student engineer will be able to attend classes in nearly all his required subjects without straying far from the quadrangle. For the present, however, mathematics will continue to be taught in University Hall, the old main building just west



THE COORDINATE AXES

of the Administration Building, and physics in Mendenhall Laboratory on the south side of the oval.

Engineering is fourth in size among the eleven colleges of the University. Enrollment this year is 1,553. Baccalaureate and professional degrees are now given in ten subjects: architecture, architectural engineering, ceramic engineering, chemical engineering, civil engineering, electrical engineering, industrial engineering, mechanical engineering, metallurgical engineering, and mine engineering. In addition there is a course leading to the degree of bachelor of engineering physics. Since the founding of the school 3,610 have graduated, distributed by degrees and years as shown in the following table:

GRADUATES IN ENGINEERING, THE OHIO STATE UNIVERSITY

Year	Arch.	Arch. Engr.	Cer. Engr.	Chem. Engr.	Civ. Engr.	Elect. Engr.	Mech. Engr.	Min. Engr.	Gen. Engr.	Ind. Engr.	Met. Engr.	Eng. Phys.	Total
1878					1			1					2
79					1			1					2
1880					1		1	1					3
81							1						1
82								1					1
83					1		3	2					6
84					1		1	2					4
85					1		3	2					6
86					3		1	4					8
87					3		2	2					7
88					4	1	4	4					13
89					1		2	2					5
1890					2		3						5
91					2	2							4
92					7	5		1					13
93					9	9	2	1					21
94					7	8	1	4					20
95					9	5	2	1					17
96					11	7	4	6					28
97					4	13	12	3					32
98					8	11	7	2					28
99				1	7	7	6	3					24
1900			1	1	4	11	9	3					29
01				7	9	4	6	2					28
02			3	5	13	6	11	6					44
03	1			3	14	8	17	7					50
04	2		4	4	12	18	15	5					60
05	1		2		17	20	19	9					68
06				2	19	18	15	9					63
07	2		3	6	25	30	15	11					92
08	1		13	5	28	23	15	11					96
09	5		19	7	27	27	16	12					113
1910	4		12	6	35	16	20	15					108
11	5		14	11	18	34	22	14					118
12	9		12	14	18	27	19	8					107
13	11		8	9	24	28	18	12					110
14	8		6	20	26	29	22	11					122
15	8		8	15	21	20	28	2	1				103
16	15		8	14	21	25	24	6	4				117
17	14		10	17	23	21	21	6	3				115
18	3	10	8	14	14	12	10	4	5				80
19	1	1	5	7	9	23	7	2	3				58
1920	11	3	9	24	39	19	22	6	18				151
21	9	8	6	23	28	35	43	1	14		5		172
22	2	9	10	22	27	25	39	7	14		4		159
23	6	14	12	41	34	53	56	11	4		10		241
24	8	7	5	18	40	53	50	5	1		7		194
25	12	10	12	28	46	52	34	8			6	1	209
26	5	7	13	10	31	54	35	12	1		8		176
27	9	12	27	12	32	49	24	2		2	7	2	178
28	10	7	23	13	45	51	30	4		7	7	5	202
	162	88	253	359	782	859	717	254	68	9	54	8	3,610

Columbus is a good place to study engineering. A city of 300,000, a railroad and manufacturing center, it affords many opportunities for doing engineering work and for studying engineering structures and operations. Paving, bridge building, building construction, grade-crossing elimination work are constantly in progress. The two large storage dams in the Scioto River, the water treatment plant, and the sewerage system afford excellent examples of the work of hydraulic and sanitary engineers. Ohio is a center of the clay and pottery industry. The first school of ceramics in the United States was that established at Ohio State. Mining and quarrying work may be seen not far from Columbus. The diversified industries of the city give opportunity for observation of the carrying on of all the branches of engineering work.

Columbus is a center of engineering research. In the engineering experiment station investigations and tests are constantly in progress. Ceramic engineers will find much to interest them in the University's experimental clay products plant at Roseville, 70 miles from Columbus. Extraordinary facilities for metallurgical research will be afforded in the Battelle Memorial Institute, now being erected within a mile of the engineering quadrangle.

The college of Engineering of The Ohio State University is one of the largest and most important colleges of a large and important institution. Its buildings and facilities are notably well adapted for instruction in the various branches of engineering. It is important for what it is and what it is becoming, for what it has done and what it is preparing to do, for its successful alumni and former students, and for the engineers of the future whom it will help develop into useful citizens.

NON-COLLEGE TECHNICAL EDUCATION

Statements have appeared in ENGINEERING EDUCATION from time to time about the study of non-college technical education that is being conducted under the auspices of the Society for the Promotion of Engineering Education, and under the direction of a committee of advisors. Mr. W. E. Wickenden, Director of Investigations of the Society, will speak on one phase of this subject at a session which will be held at 2:00 P.M. on May 13, 1929, in Rochester, New York. The members of the Society will be welcomed, and all members in the vicinity are urged to attend.

The subject of Mr. Wickenden's address is "The Technical Institute—European Examples and Their Significance to American Education." Mr. Wickenden has spent some months in Europe on this study, while members of his staff have been at work in this country.

Mr. Virgil M. Palmer, Engineer of Industrial Economy, Eastman Kodak Company, Rochester, New York, who has had much to do with the analysis of industrial conditions in Rochester with respect to education, will give a paper which is looked forward to with great interest. His subject will be "Industry Specifies Its School Training Needs." Rochester has done much in education for industry, and all who are interested in this important phase of education will profit by hearing Mr. Palmer's paper, or by reading it when it appears.

For some years past, a comprehensive investigation of education for industry has been made in Great Britain, and one of the papers of this session will be read by Mr. Wm. W. Conant, of Washington, D. C., and will give in brief form the leading conclusions drawn from this investigation.

All in all, the program of the session at Rochester, which, incidentally, is part of the program of the Spring Meeting of the American Society of Mechanical Engineers, is very attractive, and it is hoped that many members of the Society will take advantage of the cordial invitation to be present and to take part in the discussion of the papers.

THE PREPARATION OF LABORATORY REPORTS

BY ARTHUR L. ALBERT, *Instructor of Electrical Engineering*
Oregon State College, Corvallis, Oregon

Synopsis.—This paper covers the method of preparing laboratory reports by students of the Electrical Engineering Department at Oregon State College. The method is based on the recommendations of the American Institute of Electrical Engineers for preparing technical papers for presentation and publication. After two years of trial, the method outlined in this paper has proved to be very successful.

Introduction

Modern engineering work is characterized by the large number of technical reports and papers produced. Therefore, a graduate entering the engineering field who has not received adequate training in report writing will be greatly handicapped. Realizing this, most engineering schools require that reports are prepared by the students covering the laboratory experiments they perform. These reports vary from rough pencil work with freehand drawings and curves, to formal engineering reports of the highest type. It is the purpose of this article to discuss the preparation of laboratory reports, and to outline the method used by the students of the Electrical Engineering Department at Oregon State College.

Requirements for Report Writing

The electrical engineering students are requested to prepare their laboratory reports in accordance with the recommendations of the American Institute of Electrical Engineers as outlined in the pamphlet issued by the Institute entitled "Suggestions to Authors." All of the suggestions do not apply since the pamphlet is designed to explain the procedure for preparing papers for publication. However, the general form, terminology, spelling, abbreviations, and symbols are strictly followed by the students. Copies of the pamphlet are made available to the students, and in addition a mimeographed outline discussing in detail the exact method is fur-

nished. Also, they are encouraged to observe articles appearing in the *Institute Journal,* and to prepare their laboratory reports from a professional rather than from an academic standpoint. This method has been used for two years; it has been enthusiastically received by the students, and is satisfactory in very respect.

Advantages of the System

If the method outlined in the preceeding paragraph is not followed, there are two other possibilities. First, that of not specifying a procedure for report writing, and second, specifying some purely arbitrary set of standards. Employing no standards may lead a few students to develop additional initiative in report writing; however, experience has shown that as a whole this results in poor and unsatisfactory reports, and is therefore undesirable. The second method, having arbitrary standards, is also unsatisfactory for two major reasons. First, the students do not appreciate a purely arbitrary form which may have little practical value, and second, the instructors are reluctant to enforce a system which they realize is of questionable value in practical engineering work. However, since the Institute establishes standards for the electrical profession, there can be no doubt by either students or instructors as to correctness of the method, or to its practical applications.

The students derive many other benefits if the Institute recommendations are applied to preparing laboratory reports. Not only do they become familiar with the best engineering practice, but also they become interested in preparing papers for Student Branch meetings. Furthermore, they develop a confidence in writing which is of great value to them in practical engineering work. A graduate entering the employment of a large company is confronted with considerable routine, and when called upon to write a report or a memorandum is not certain of the form to use. If however, the method for preparing papers as specified by the Institute is known, the graduate will feel assured that if this form is used it will be correct.

As previously mentioned, preparing laboratory reports according to the Institute suggestions also assists the laboratory instructor. The responsibility for the system does not lie with the instructor, and the students, realizing the practical importance of the method, find little fault with the rather rigid requirements. The instructor has the authority of the Institute for the various usages, and is thus fortified against any possible dissatisfaction which may arise. This is certainly not the condition when a purely arbitrary form is used for reports.

This method of administering laboratory report work is very favorable to the Institute. It brings the work of the Institute before the students at the time of beginning electrical work, and the habit of regarding the Institute as final authority is early formed. Furthermore, an examination of the papers published in the *Institute Journal* will show that even among prominent engineers there is a tendency to deviate from the method specified by the pamphlet "Suggestions to Authors." If electrical engineering students are taught the Institute requirements, such deviations will be greatly reduced in number.

It may appear that the method outlined in this paper will tend to discourage initiative and creative ability on the part of the students. Such however is not the case. An examination of the requirements of the Institute will show that there is ample provision for individual expression.

Conclusions

In conclusion, the practice of having electrical engineering students prepare their laboratory reports in accordance with the requirements of the American Institute of Electrical Engineers for technical papers has been very satisfactory. The students are ardent supporters of the method; the administration of laboratory report work by the instructors is made easier; the Institute and its work are favorably introduced to the students, and they are taught a useful method rather than an arbitrary one which is useless after graduation.

A PROPOSED PROGRAM FOR IMPROVEMENT OF THE ENGINEERING TEACHER

BY CLAIR V. MANN *

As a result of the nation-wide survey of engineering education the past four years by the Society for the Promotion of Engineering Education, much has been said of the possibility of broadening and enriching engineering education through the definite improvement of the engineering teacher.

We think it likely that the present-day teacher of engineering is fairly well prepared—perhaps as well prepared as any other class of college instructors—at least in the matter of a knowledge of the subject-matter of the courses which are taught. If a fair criticism may be made of engineering teachers, it is probably that they could be better prepared in the way of presenting the facts of the courses as they know them. This would involve both a more ready command of good English speech than the average engineering teacher has, and more skill in methods of teaching. A very definite advance can be made in the matter of measurement of results of engineering instruction and diagnosis of student difficulty in particular courses, by adoption of scientific techniques in administration of daily, term, and semester tests, quizzes, and examinations. This class of teachers should become familiar with the field of modern educational testing, and prepared to handle student personnel problems, in particular those involved in the case of students of the first two years.

A criticism of a much different character, in addition to the above, may be leveled at those teachers—by no means all of them, but some of them—who are giving instruction to engineering students in such subjects as English, languages, chemistry, physics, mathematics, and economics. That criti-

* Head of Dept., and Professor of Engineering Drawing, Missouri School of Mines, Rolo, Mo. On leave of absence, 1928–9, at State University at Iowa.

cism is, that to many such teachers, the concept of making their instruction contribute definitely to the making of good engineers is a foreign, unworthy object. The position here taken is that such teachers would become vastly more effective and interesting to engineering students if they were required —no, rather if they had voluntarily decided—to take certain fundamental "survey" or "appreciation" courses, perhaps a seminar, in "The Nature and History of Engineering"; "History of Engineering Education"; "The Place of the Engineer in Modern Life"; "The Significance of Engineering in Past and Present World Civilization." Such courses, and others like them, should endow those teachers who have not had definite engineering training with an appreciation and liking for engineering work and instruction that they do not now possess—either such studies should result thus, or such teachers should be found guilty of not being interested in their profession, and should be required to give up their positions as instructors of engineering students, and move into some other field more in accord with their personal interests. We should probably as well find many an instructor of the technical engineering subjects guilty of failing to inspire his students, and he too should find other more congenial fields of activity.

The position is here taken that the matter of training and qualifications of college teachers of engineering is a thing of more importance than it has been assumed to be in the past; also that it is more important for teachers of freshmen and sophomores to have specialized training in their teaching functions than that the teachers of upper classmen should be so trained. The former group has the difficult task of making university students out of raw material from the high school, whereas the latter group of teachers meets students who have been trained, to a greater or less degree, to work for themselves. Such students can better survive in junior and senior classes than can students of the first two years under the conditions now in force. The teacher of freshmen and sophomores needs to be the very best sort of a *teacher* to be found in the entire engineering college. He needs every bit

of engineering knowledge and exprience he can get—but he needs badly as additional preparation a keener apreciation of his teaching and personnel problems than he now has.

It is no new thing to suggest the idea that the alert, sympathetic, discerning graduate college, cooperating to the fullest extent with the colleges of engineering and education, has a most important function to perform in enabling wide-awake and aggressive engineering teachers to round out their preparation for more effective teaching. Many times various of our prominent engineering educators have gone on record as being in favor of some such program. The minutes of the 1922 annual convention of the Society for the Promotion of Engineering Education, at the University of Illinois, contain in particular such suggestions. The present article makes no claim to originality in regard to the ideas expressed, except perhaps in the matter of bringing into more crystallized form concepts already moulded in the rough.

Five groups of individuals teaching or intending to teach courses to engineering students are conceived of as being capable of deriving benefit from definite programs in teacher training in the realm of engineering education, as follows:

1. The promising undergraduate student in engineering, whom alert teachers should learn to select, who may be interested by his instructors, or who may really want (on his own initiative) to take up engineering education as his profession. This student could gain much from systematic observation of the methods used by his teachers in the engineering college, and no doubt could suggest significant improvements at times. He should be given opportunity to enroll in an elective course calling for a report on the teaching methods he has observed. For free electives, he could be allowed to include in his engineering curriculum two or three of the fundamental educational courses named in later programs, such as general psychology, statistical methods, and construction of tests. These would not do violence to his strictly engineering training. His diploma could take account of this type of preparation, or perhaps better still he could be given an appropriate certificate. If possible for him to select the

particular field in which he desired to teach, he could take special instruction in the teaching of that subject.

2. Graduates of colleges other than engineering who may wish to teach courses in English, languages, chemistry, economics, mathematics, or physics *to engineering students.* Here would be excellent opportunity for select men majoring in professional education. Those of this general group who have not had them can profitably take—should be required to take—courses in statistical method in education, theory and practice of constructing tests for engineering students, general psychology, and personnel problems. A vital requirement should be a thorough seminar course or thesis in "Nature and History of Engineering," and "History of Engineering Education." *A course in English speech,* study of methods in the specific field selected for teaching, study of the significance of engineering in past and modern civilizations are other essentials. Thesis should not occupy over one fourth of the year's work required for the degree Master of Science in Engineering Education, if indeed, there should be any "Thesis" at all.

3. Graduates of the engineering college who have had little or no practical engineering experience, who have not taught. The program outlined for group 2 is mostly applicable. However, a period spent in practical engineering work, either in connection with teaching, or preceding it, is emphatically to be required in conjunction with a graduate program such as is here propósed. Engineering background is a first requirement in the successful engineering educator, particularly as a teacher of the technical engineering subjects, and little less for any other subject that such a graduate would be likely to teach.

4. This group comprises individuals who have had several years experience in teaching, or perhaps in engineering practice, who also have the B.S. degree with perhaps the professional engineering degree or a master of science degree, who may wish definitely to prepare for more effective work as a teacher, or to be in line for appointment as head of a department of instruction. This group may well include individ-

uals intending to work in fields other than strictly engineering subjects, as in English, for example. Selected men from the college of education should be included. These individuals could profit from a program finally culminating in the degree of Ph.D. in Engineering Education. The primary aim of this program will be to provide a good general background in the history of engineering, its nature and subdivisions; its relations to social and economic progress both of the past and the present. Such teachers need a broader outlook upon these phases of their teaching than they now have. But the end product of such a program must be a man practical minded enough to "register" with the engineering profession—a thing that must never be lost sight of. This program should cover the material outlined in Programs 2 and 3 above, and in addition could well include more history of science, invention, and engineering; history of civilization; with special emphasis on the place of science, invention, and engineering in it; economic history of the United States; a good survey course in labor problems and other personnel problems of industry; social psychology; and the place of the engineer as a leader in modern world progress. Matriculates should be made familiar with the results of the recent study of engineering education completed by the Society for the Promotion of Engineering Education, and should know the details of such problems as the construction of engineering curricula; departmental administration in the engineering college; qualifications of teachers in engineering education; departmental budget and equipment; and any specific course material they may be called upon to teach in their particular field. Theses should be laid in some field definitely related to *teaching* problems in that field—*not to problems of research in engineering* science. A program in engineering education is not the appropriate field for thesis work of that nature.

5. Individuals who have had mature teaching and practical engineering experience, who desire to prepare ultimately to hold positions as deans of colleges of engineering, or desire training as specialists or experts in some particular phase of engineering education. The degree of B.S. in engineering

should be required normally, and professional engineering degrees are highly to be desired of matriculants for this program. The program should also be opened to *selected* men in professional education or other significantly related fields, who show special fitness and exhibit special interest or promise in this line. For this group, most of the program outlined in 4. above would apply. Much greater emphasis should be placed upon the broader aspects of engineering, engineering education, and its significance in modern and future life. Men majoring in this field should have, or acquire as a part of the program, considerable facility of speech, and ability to make public addresses while feeling at ease. Courses in University Administration covering organization and administration of the modern engineering college and its departments should receive emphasis. Theses can well be written in these fields. Budget and financial problems of the engineering college; equipment and plant and campus planning problems should have attention. Personnel problems relating to preparation of entering students and character training; teaching and student problems throughout the entire engineering course; curricula construction; examination methods and practices; qualification and selection of engineering teachers —all these are fertile fields for study, research, and theses. Relations of the engineering college to the other units of the University, and to the profession of engineering and to industry, are worthy of study. The problem of organization of human society for control and utilization of natural forces and resources; and means for evaluation of the benefits to society accruing from these activities should occupy a place not least in this program. *In large measure the present and future deans of the engineering colleges* are going to be responsible for engendering that spirit which shall result in the wise use and control of all engineering activity, *for the benefit, and not for the exploitation and destruction* of the human race. Not only must engineering deans and teachers gain this broader outlook upon their work as trainers of leaders, but engineers themselves, as the natural leaders in all things pertaining to the planning and construction of industrial ma-

chines and public works, must gain a much broader, more understanding viewpoint in regard to all these activities. Theses of matriculants in the program here suggested should be laid in the broader fields of engineering education, at least until they are adequately covered. Some will be laid in the field of personnel or administrative work of the engineering college. Others in the field of the social and economic content of engineering curricula. In every possible way, matriculants in this specific program should be helped to broaden and enrich their knowledge of past and modern culture, and their conception of social, economic, and spiritual values.

The aggressive engineering college and the alert graduate college, working together in a helpful spirit of cooperation, and with the professional college of education, will be interested in aiding the present teaching force in the engineering colleges to avail themselves of such programs. They will seek to encourage that spirit among engineering educators which shall stress not less than formerly the need of adequate training and practical knowledge of engineering—but which shall stress far more emphatically the new and modern need of a more general, adequate preparation for the effective performance of the *teacher* function of the engineering educator. Particularly will this be so in the case of those engineering teachers to whom instruction of freshmen and sophomore students in the engineering college is entrusted.

THE 1929 CONFERENCE ON MECHANICS, JUNE 22 TO 27, 1929

The teachers of mechanics have taken the initiative in planning several sessions for a conference of mechanics to be held at Ohio State University immediately after the annual meeting of the S. P. E. E. in June. This conference will be a natural follow-up of the summer sessions held in 1927 at Cornell University and the University of Wisconsin and of the meetings on mechanics at Chapel Hill in 1928. It will afford an opportunity for the ample discussion of various open questions in the teaching of this subject. The meetings this June will be open to all who wish to participate in the discussions. Ideal conditions will not be held up for inspection—but rather actual teaching methods and objectives will be presented to show what can be done with the time now generally given to the teaching of mechanics.

The Committee on Arrangements for the approaching conference has been giving careful consideration to the details of procedure and program to be followed. It seems best to take up first for discussion the questions on objectives in the study of mechanics of the tentative program printed in the February Journal, and then such additional questions on subject matter, class room methods, etc., as may seem most important and as time will permit.

As the time is limited it is hoped that each one who attends the conference will come prepared to state his views on each question, with his reasons therefor. It seems desirable that so far as practicable these discussions be prepared in written form in advance. This will greatly facilitate the preparation of a permanent record of the proceedings of the conference.

The committee requests that every one who is expecting to attend the conference notify some member of the committee of this fact, indicating what questions he is most interested in and will discuss. Suggestions of any kind regarding the conference will be welcomed by the committee, either before

the convention in June, or at the time of holding the conference.

J. E. BOYD,
S. B. FOLK,
E. R. MAURER,
A. P. POORMAN,
E. W. RETTGER,
N. C. RIGGS,
SHERMAN M. WOODWARD,
Chairman.

OBITUARY

Frank Mason Comstock, head of the department of Descriptive Geometry and Drawing at Case School of Applied Science, died March 6, 1929. Dr. Comstock was apparently in good health. He took lunch with Dr. Howe and other members of the faculty at noon the day before and was at his office both morning and afternoon. In the morning, March 7, he went to tend the furnace about 8:00 A.M. and was overcome by a paralytic stroke from which he was not able to rally. He died at 9:15 A.M.

His death is a great shock to students, faculty, alumni—all who knew him. His place will be hard to fill. For thirty eight years he taught descriptive geometry and drawing, also classes in English when the college was young. He was chairman of the Committee on Admissions for many years, and his was a keen vision in the selection of applicants.

Dr. Comstock came to Case in 1891. He was a graduate of Union College and has many degrees, including Bachelor of Arts, 1876; Master of Arts in 1879; soon after the degree of C. E.; 1891, Doctor of Philosophy; 1926, the honorary degree of Doctor of Humane Letters.

In 1912–13 Dr. Comstock served the college as Acting-President during the absence of Dr. Howe for that year. He was a shrewd and just executive as well as a brilliant teacher.

He was born May 20, 1855, in Le Roy, New York. From 1879 to 1891 he served as principal of the Le Roy Academic Institute. In 1876 he took active part in the New York Adirondack Survey. He was a member of the American Forestry Association, the Canadian Forestry Association, and The Society for the Promotion of Engineering Education. He was a frequent contributor to technical periodicals.

During Founder's Day celebrations on February 25, Dr. Comstock went to Canton and there addressed a large group of Case alumni. Both among alumni and about school everyone called him, "Comey"—a title of endearment.

He is survived by his widow and one son, William S. B. Comstock of New York.

"COLLEGE NOTES"

BY F. L. BISHOP

Secretary of the Society

The constantly increasing desire of the colleges and the universities to increase the value of their curricula for the benefit of the country at large is manifested in College Notes, published each month in the JOURNAL OF ENGINEERING EDUCATION. In these College Notes you will find new courses offered; new equipment secured; new buildings erected; additions to the faculty; meetings held and attended; faculty members taking graduate courses in other schools; increase in library facilities; and so on. But in no case is any of these things done to add prestige to one college or university or to attract students to a particular school.

The feeling which the writer gets in reading these Notes is that each school through its faculty members—composed mostly of members of the S. P. E. E.—is striving to broaden and enrich engineering education. But this is not the only desire of these schools. Between the lines of these Notes one senses the desire of each school to prepare its students better to meet the demands of industry and citizenship; to meet competition fairly and squarely. Never before has it seemed to me that the human element entered so much into our work. You feel that each instructor has a human interest in his students; that he is endeavoring to bring out the best that is in the student and to give to the student the best that is in the instructor.

In doing all these things the instructor is not only a better citizen in his community but he is sending better citizens to other communities and thus increasing the power of the engineer.

COLLEGE NOTES

Bucknell University.—Cooperating with the Chemical Engineering Alumni Association of Bucknell University, an extensive survey has been conducted in order to determine the nature of the professions in which the graduates of the Chemical Engineering Department are engaged. It was largely due to the numerous requests from various colleges and universities, contemplating the institution of a Chemical Engineering Course, for such a directory, that this analysis has been made.

This survey has been conducted by Dr. S. C. Ogburn, Jr., head of the Chemical Engineering Department of Bucknell University, and some interesting facts have been obtained. The material for this study has been collected from University Alumni records, and from personal communications, and gives an authentic record of all the men who have graduated from the department with a degree of B.S. in Ch.E., since the institution of the course in 1913, until 1928.

The entire number of graduates during the interval named has been divided roughly into three divisions: (*a*) those having occupations in which their professional training predominates; (*b*) those having occupations in which their professional training does not predominate; and (*c*) those for whom no occupational record could be obtained. These divisions are further subdivided according to the specific type of occupation, and in each of these latter cases the percentage of the entire graduate body from the department in this field of endeavor was determined.

The following is a summary of the data obtained:

Occupations in which the professional training predominates.

a. Chemical Engineers and Industrial Chemists	49.74%
b. Research Chemists	6.38%
c. Teachers of Chemistry	11.34%
d. Chemical Salesmen	4.26%
e. Chemical Lawyers	0.71%
Total	72.43%

Occupations in which the professional training does not predominate.

a. Industrial work, non-chemical	4.88%
b. Non-industrial, non-chemical	12.05%
Total	16.93%
c. No occupation record available	10.64%

It should be noted that this data covers the period from 1913 to 1928 inclusive. The first degree of B.S. in Ch.E. was given in 1913. A consideration of these facts presented will show that the greater majority of the graduates from the Department are using their technical knowledge in their present occupation. Only 16.93% of the entire graduate body have abandoned the field of chemical endeavor and for 10.64% no occupational record could be obtained. Of these 10.64% it is quite probable that one-half of the number are actively engaged in professional chemical work. The outstanding fact shown was that out of approximately 150 graduates of the Chemical Engineering Department, 72.43% of these are actively engaged in professional chemical work.

The **Kansas State Agricultural College** continues to enjoy a relatively large enrollment in its Engineering Division. In 1926–27, the number mounted to 1019, while this year the enrollment totals slightly less, being 957 to date.

Several, though comparatively few, changes have taken place in the engineering faculty. Professor H. B. Walker, head of the Department of Agricultural Engineering, resigned to take a similar position with the University of California. Professor F. C. Fenton, from Ames, Iowa, was secured to fill this vacancy. In the Department of Architecture, Professor F. A. Kleinschmidt and Instructor T. A. Chadwick resigned, Professor Kleinschmidt being made head of the Department of Architecture at Texas Technological College and Mr. Chadwick going to the industries. C. L. Carjola from the University of Minnesota was engaged for work in this department. Professor F. A. Smutz who was granted a year's leave of absence from the Department

of Machine Design is back on duty this year. During the current year Professor Benjamin Spieth of the Department of Applied Mechanics was granted a leave of absence to go into the industries for some special work on testing heating units.

Two new textbooks by members of the engineering faculty have been completed to the point of being put to use in the classroom. One by F. A. Smutz and R. L. Gingrich covers the subject of Descriptive Geometry, and the other on "Direct-current Machinery" have been prepared by J. L. Brenneman and R. G. Kloeffler.

The Engineering Experiment Station, of which R. A. Seaton, Dean of Engineering, is also Director, is continuing active work on 15 definite research projects as follows: Sewage Disposal Systems; Belt Lacings; Use of Straw as Fuel; Small Brass Furnaces; Durability of Concrete; School Shops for Vocational Agriculture; Short Time Test for Sand; Storage Batteries; Farm Homes; Concrete Silos; Valuation Characteristics of Sand and Concrete; Reclamation of Oils; Economics of Rural Line Construction; Refrigeration in the Home; Harvesting and Baling Hay. Besides these, there are a number of other projects on which some preliminary surveys have been made.

One of the outstanding projects completed last year was the Rural Electrification Laboratory at Larned, Kansas. At this place much important work was done relative to rural electrification in Kansas.

Plans are under way for an extensive addition to the engineering building for the housing of the laboratories and machinery of the Agricultural Engineering Department. This, however, will require action on the part of the state legislature which may not be forthcoming. In case our hopes do materialize, the crowding now existing to some extent in the other departments will be greatly relieved.

The completion of the new power plant for full operation next year will give additional room for the Department

of Mechanical Engineering, which department will occupy the space now taken by the old power plant.

K. S. A. C. has good reason to look forward to continued usefulness along the lines for which the school was established.

University of Kansas.—Engineer's Day was celebrated at the University of Kansas on March 14th. The general subject was Aviation, and the auditorium was filled at both morning and afternoon sessions by students and visitors who listened to a series of discussions on various phases of the subject.

The Baron Shiba High-Speed Film showing the action of air currents impinging upon models of airplane wings was shown twice.

In the evening Mr. C. W. Stone, Consulting Engineer of the General Electric Company, and a former student at the University of Kansas, explained and demonstrated the photophone to an audience of about 2000.

University of Minnesota.—John R. DuPriest is the head of the Mechanical Engineering Department, coming to Minnesota from Oregon Agricultural College where he held a similar position.

J. M. Bryant comes to Minnesota from the University of Texas to head the Electrical Engineering Department.

C. M. Jansky chief of the radio division in the electrical engineering department has been appointed as a member of the federal radio commission by President Coolidge.

R. M. Hazen has resigned to assume duties as research assistant to the chief engineer of the Wright Aeronautical Corporation, where he is in charge of engine testing and development.

G. O. Hoglund comes to Minnesota from the Navy Department at Washington, D. C., to succeed Mr. Hazen.

George Swendson assumed his duties as the head of the electrical Engineering department at Michigan College of Mines at the beginning of the present school year. He is

succeeded by Dr. H. E. Hartig who transferred from the department of Mathematics and Mechanics at Minnesota to the Electrical Engineering department.

Frank Morris formerly assistant Director of the Experimental Engineering laboratories is in charge of research in the laboratories of the Insulite Co. Mr. A. B. Algren is his successor at the Univ. of Minn.

J. I. Parcel, division of structural engineering, Civil engineering department is absent on Sabbatical leave this year.

Massachusetts Institute of Technology.—Professor Werner Heisenberg, Director of the Institute of Theoretical Physics, of the University of Leipzig, was in residence three weeks at the Institute, delivering a series of lectures on "Recent Developments in Quantum Mechanics," and Dr. Theodor Rehbock, Professor of Hydraulics at the Technische Hochschule of Karlsruhe, has just completed a series of nine lectures on "Hydraulic Experimentation." The visit of these two eminent scientists has been a source of inspiration to a large number of students and members of the instructing staff who have attended the lectures.

The Fifth and Final Whiting Concert for this year was given on Tuesday night, March 26. The concerts conducted for the last four years by Mr. Arthur Whiting have become a noteworthy part of the Institute life. The attendance and enthusiasm of both students and faculty are evidence of their appreciation of the high character of these musical offerings.

NEW MEMBERS

BAKER, CHARLES L., Instructor in Mathematics and Mechanics, University of Minnesota, Minneapolis, Minn. O. M. Leland, W. E. Brooke.

BARNES, RALPH M., Assistant Professor of Industrial Engineering, University of Iowa, Iowa City, Iowa. C. C. Wiliams, S. M. Woodward.

BECK, FRED J. Instructor in Electrical Engineering, Yale University, New Haven, Conn. Chas. F. Scott, R. G. Warner.

BLACKBURN, HENRY W., Assistant Professor of Mechanical University, Syracuse University, Syracuse, N. Y. S. T. Hart, Louis Mitchell.

BRENKE, WILLIAM C., Professor of Mathematics, University of Nebraska, Lincoln, Nebr. O. J. Ferguson, Jiles W. Haney.

CAMERON, HUGH L., Instructor in Mechanical Technology, Pratt Institute, Brooklyn, N. Y. S. S. Edmands, Arthur C. Harper.

CONRAD, ALBERT G., Instructor in Electrical Engineering, Yale University, New Haven, Conn. Chas. F. Scott, A. E. Knowlton.

EGILSRUD, FRIDTJOF S., Instructor in Mechanical Technology, Pratt Institute, Brooklyn, N. Y. S. S. Edmands, Arthur C. Harper.

GWIAZDOWSKI, ALEXANDER P., Assistant Professor of Shop Practice, University of Michigan Ann Arbor, Mich. O. W. Boston, F. L. Bishop.

HARKNESS, DANIEL H., Instructor in Civil Engineering, University of Nebraska, Lincoln, Nebr. Clark E. Mickey, Jiles W. Haney.

HOGLUND, GUSTAV O., Assistant Professor of Aeronautical Engineering, University of Minnesota, Minneapolis, Minn. O. M. Leland, B. J. Robertson.

ISENBERG, DAVID A., Head, Department of Physical Elements of Engineering, Pratt Institute, Brooklyn, N. Y. S. S. Edmands, A. C. Harper.

ISRAELSEN, ORSON W., Professor of Irrigation and Drainage, Agricultural College of Utah, Logan, Utah. Ray B. West, F. L. Bishop.

JONES, CHARLES B., Instructor in Forging and Heat Treatment, Pratt Institute, Brooklyn, N. Y. S. S. Edmands, John W. Burley.

KAESTLE, FRANCIS L., Instructor in Electrical Engineering, Yale University, New Haven, Conn. Chas. F. Scott, R. G. Warner.

KEATOR, FREDERIC W., Assistant Professor of Mechanical Engineering, Yale University, New Haven, Conn. Chas. F. Scott, R. G. Warner.

KIMBERLY, EMERSON E., Assistant Professor of Electrical Engineering, The Ohio State University, Columbus, Ohio. F. C. Caldwell, A. Puchstein.

LINDSAY, FRANK B., Instructor in Mathematics and Mechanics, University of Minnesota, Minneapolis, Minn. O. M. Leland, W. E. Brooke.

MCNAMARA, FRANCIS T., Assistant Professor of Electrical Engineering, Yale University, New Haven, Conn. Chas. F. Scott, A. E. Knowlton.

OTHUS, JAMES C., Assistant Professor of Mechanics and Materials, Oregon Agricultural College, Corvallis, Ore. H. S. Rogers, D. S. Kimball.

PUERNER, RUSSELL E., Assistant Professor of Machine Design, University of Wisconsin, Madison, Wis. L. F. Van Hagan, P. H. Hyland.

SALZER, GEORGE W., Professor of Descriptive Geometry and Technical Drawing, Colorado School of Mines, Golden, Colo. W. J. Risley, M. F. Coolbaugh.

SCHERBERG, MAX, Instructor in Mathematics and Mechanics, University of Minnesota, Minneapolis, Min. O. M. Leland, W. E. Brooke.

THOMSON, WILLIAM H., Instructor in Pattern Making, Pratt Institute, Brooklyn, N. Y. R. Burdette Dale, S. S. Edmands.

WALTHERS, HARRY V., Instructor in Mechanical Engineering, University of Nebraska, Lincoln, Nebr. O. J. Ferguson, Jiles W. Haney.

BOOK REVIEWS

Analytic Mechanics. By JOSEPH B. REYNOLDS, Ph.D. Prentice-Hall, 1929. 340 pages. $4.00.

The field of Mechanics is customarily divided into three parts—Statics, Kinematics and Kinetics. In the volume under review only the second and third parts are considered, a knowledge of statics being pre-supposed.

The author is a mathematician rather than an engineer, and his mathematical bias in the statement and solution of problems is quite marked. The engineer encounters a set of physical conditions and endeavors to express them by mathematical forms. The author prefers in many cases to state the problem in mathematical language and then interpret the equations in terms of physical conditions.

The author assumes a facility in the use of the calculus greater than is ordinarily found in undergraduates. The numerous problems furnish an excellent drill in the application of the calculus, though many of them may be regarded as mathematical exercises rather than practical engineering problems.

The treatment of the topics of Kinematics and Kinetics is clear, logical and thorough. The reviewer, however, regrets the omission of any mention of Coriolis' law in what is otherwise an excellent discussion of the subject of acceleration. This law is of great value in the study of accelerations in mechanisms, and should be included.

The figures leave something to be desired in the way of appearance. The soft paper used does not take a good impression of the cuts, so that lines are not sharp and clean, and the lettering is often blurred. The drawing is not always of the best. The text is unusually free from typographical and other minor errors.

This book may be regarded as an excellent text for a course following a preliminary study of Statics, and for students who are well grounded in Mathematics.

J. A. D.